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# Palynological and Carbon-Isotopic Techniques for Reconstruction of Paleommarsh Salinity Zones.

Gail Lois Chmura

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**Palynological and carbon-isotopic techniques for reconstruction  
of paleommarsh salinity zones**

**Chmura, Gail Lois, Ph.D.**

**The Louisiana State University and Agricultural and Mechanical Col., 1990**

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PALYNOLOGICAL AND CARBON-ISOTOPIC TECHNIQUES  
FOR RECONSTRUCTION OF PALEOMARSH SALINITY ZONES

A Dissertation

Submitted to the Graduate Faculty of the  
Louisiana State University and  
Agricultural and Mechanical College  
in partial fulfillment of the  
requirements for the degree of  
Doctor of Philosophy

in  
The Department of Marine Sciences

by  
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May 1990

**To Mom and Dad**

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## TABLE OF CONTENTS

	Page
DEDICATION.....	ii
ACKNOWLEDGEMENTS.....	iii
LIST OF TABLES.....	vi
LIST OF FIGURES.....	viii
ABSTRACT.....	xi
INTRODUCTION.....	xiii
COPYRIGHT PERMISSION.....	xvii
Chapter 1: An Inventory of $^{13}\text{C}$ Abundances in Coastal Wetlands of Louisiana, USA:	
Vegetation and Sediments.....	1
Chapter 2: Pollen in the Lower Mississippi River.....	9
Chapter 3: Modern Pollen Assemblages in Marshes of Coastal Louisiana, USA.....	28
Chapter 4: Classification of Paleommarsh Salinity Zones: A Comparison of $\delta^{13}\text{C}$ and	
Palynological Techniques.....	86
SYNTHESIS AND CONCLUSIONS.....	112
Appendix 1: Pollen and Spore Counts from LOOP Surface Marsh Samples.....	114
Appendix 2: Pollen and Spore Counts from Falgout Canal Core, Terrebonne Parish,	
Louisiana.....	124
VITA.....	127

## LIST OF TABLES

Table		Page
 CHAPTER 1		
1	Accuracy of standard $\delta^{13}\text{C}$ determinations (relative to PDB standard) over the duration of this study.....	3
2	$\delta^{13}\text{C}$ values (relative to PDB standard) used to generate predicted ranges for marsh plots based on plant species present.....	3
3	Range and mean of sedimentary $\delta^{13}\text{C}$ for fresh, brackish and salt marshes. Water salinities are those reported by Chabreck (1972).....	4
4	Biomass (percent) by species in relation to sediment $\delta^{13}\text{C}$ values (relative to PDB standard) of 0.25m <sup>2</sup> plots along a freshwater marsh transect (Only those contributing greater than 1% biomass in any one plot are listed.).....	5
5	Biomass (percent) by species in relation to sediment $\delta^{13}\text{C}$ values (relative to PDB standard) of 0.25m <sup>2</sup> plots along a brackish marsh transect.....	5
6	Biomass (percent) by species in relation to sediment $\delta^{13}\text{C}$ values (relative to PDB standard) of 0.25m <sup>2</sup> plots along a salt marsh transect.....	5
7	Variation of $\delta^{13}\text{C}$ (relative to PDB standard) within sediments of a cypress swamp.....	6
 CHAPTER 2		
1	Proportion of total estimated annual sediment yield to the Mississippi River Basin (Keown et al., 1981).....	12
2	Major components of the Mississippi River pollen assemblage at Pointe a la Hache, average of both banks.....	17
3	Date of which first of repeated appearances are noted in 1987 aerial pollen counts. Blanks indicate that no report is given for that group.....	18

List of Tables, continued

Table	Page
CHAPTER 3	
1 Concentrations of pollen and spores in all surface marsh samples.....	43
2 Stem counts of plants in 0.25m <sup>2</sup> plots along fresh marsh transects at site FC...	46
3 Stem counts of plants in 0.25m <sup>2</sup> plots along fresh marsh transects at sites FA and FB.....	47
4 Stem count of species in 0.1m <sup>2</sup> plots along intermediate marsh transects.....	48
5 Stem count of species in 0.25m <sup>2</sup> plots along brackish marsh transects.....	49
6 Stem count of species in 0.25m <sup>2</sup> plots along salt marsh transects.....	50
7 Foraminifera concentration (per cc) in 1985 surface marsh samples.....	68
8 Classification results of discriminant analysis.....	73
9 Probability of modern analogue computed for pollen assemblages from surface marsh samples from four vegetation zones in Barataria Basin.....	74
10 Discriminant function coefficients.....	75
CHAPTER 4	
1 Prediction of paleosalinity zones based on discriminant analysis classification of surface marsh samples (chapter 3) and corresponding $\delta^{13}\text{C}$ values of samples from Falgout Canal .....	98
2 Microforaminifera in samples from Falgout Canal core.....	100
3 Carbon-13 values of species found in lower delta plain marshes as described by O'Neil (1949).....	105

## LIST OF FIGURES

Figure		Page
 CHAPTER 1		
1	Map of marsh area and sample locations in the Barataria Basin, Louisiana, USA.....	2
2	Measured and predicted carbon isotope ratios for sediment samples from clip plot study.....	4
3	Range and mean of sedimentary $\delta^{13}\text{C}$ for fresh, brackish and salt marshes. Water salinities are those reported by Chabreck (1972).....	6
 CHAPTER 2		
1	Map of sample site and tributaries on the lower Mississippi River in Louisiana	11
2	Monthly pollen assemblage with corresponding river stage <sup>1</sup> and total solids concentrations <sup>2</sup> at Pointe a la Hache, Louisiana. River discharge <sup>1</sup> measured at Tarbert Landing, Mississippi on dates indicated, except for February sample, which was taken on February 17. Pollen data are averages of samples from both banks. Note the two scales at the bottom. The upper scale is for pollen percentages (solid bars) and the lower one is for pollen concentration values (curves). Pollen concentration data for February are unavailable.....	15
 CHAPTER 3		
1	Physiographic regions of the southeastern U.S. (from Delcourt and Delcourt, 1985).....	31
2	Major forest regions of the southeastern U.S. (from Delcourt et al., 1981; redrawn from page 155 of the National Atlas, United States Geological Survey, 1970).....	32

## List of Figures, continued

Figure	Page
3 Natural vegetation regions of Louisiana ( from Newton, 1972).....	33
4 Vegetation zones and sample area locations within Barataria Basin, Louisiana.	34
5 Location of fresh (FC, FA and FB) marsh sample sites (adapted from U.S. Geological Survey, 1983a).....	38
6 Location of intermediate marsh (IC and IP) sample sites (adapted from U.S. Geological Survey, 1983a and 1983b).....	39
7 Location of brackish marsh (BC) sample site (adapted from U.S. Geological Survey, 1983b).....	40
8 Location of salt marsh (SC and SB) sample sites (adapted from U.S. Geological Survey, 1983b).....	41
9 Pollen percentages (based on total sum) of modern marsh samples from Barataria Basin, Louisiana, USA. Samples described in figure were collected in September 1985.....	45
10 Ordination of modern pollen samples from Barataria Basin marshes along discriminant functions 1 and 2.....	76

## CHAPTER 4

1 Location map for core site, Terrebone Parish, Louisiana (adapted from Penland et al. 1988 and Wicker et al. 1980).....	88
2 Deltaic lobes of the Mississippi river deltas. (Reprinted from Penland et al. 1988, adapted from figure 1, Frazier 1967:289.).....	89
3 Geomorphic diagram of the Teche and Lafourche delta complexes in the Terrebone Parish region. (Reprinted from Penland et al. 1987, redrawn and adapted from Chabreck and Linscombe 1978 and Snead and McCulloh 1984.).....	91

List of Figures, continued

Figure	Page
4 A chronostratigraphic model depicting the development of the Terrebonne coastal region as a function of sea level changes and sediment supply. (Reprinted from Penland et al. 1987.).....	92
5 Photograph of Falgout Canal core. Vertical scale in centimeters. Depth increases from top to bottom, left to right.....	94
6 Pollen, $\delta^{13}\text{C}$ and salinity class profiles of Falgout Canal Core. Grey area represents 10% exaggeration. Computation of sum explained in text.....	99
7 Ordination of samples along discriminant functions 1 and 2. A key to sample numbers may be found in table 2.....	103

## ABSTRACT

Palynological and carbon-13 analyses were studied to determine their practicality as tools for paleoecological reconstruction of marsh vegetation communities of the Mississippi delta plain. Both were calibrated on marsh surface sediment samples from four vegetation zones within Barataria Basin, Louisiana: fresh, intermediate, brackish and salt marsh. Samples were taken concurrent to vegetation sampling to allow comparison of sediment data to plant biomass and clip plot data from each of the four zones.

The  $\delta^{13}\text{C}$  of sedimentary carbon reflects the proportion of C-3 and C-4 species at a site (which corresponds to a salinity gradient in the basin). The average from all sites within each wetland type is -27.8, -22.1, -16.9 and -16.2‰, for fresh, intermediate, brackish and salt marshes. This method can distinguish among the fresh, intermediate and brackish vegetation zones.

A seasonal study of pollen carried by Mississippi River was conducted to determine the impact of river floodwaters on a marsh pollen assemblages. River water assemblages vary seasonally and reflect pollen sources from without the drainage basin. Types abundant during high river stage, indeterminate grains (assumed to represent reworked material), *Pinus*, *Quercus*, *Taxodium*, TCT, *Ambrosia* and Chenopodiaceae-Amaranthaceae type, are assumed to be over-represented in marshes subject to river flooding.

Each of the four vegetation zones has a characteristic pollen assemblage. Assemblages are not affected by over-representation of local sources, but appear to reflect the composition of the entire vegetation zone (extra-local sources). Classification of modern pollen assemblages by discriminant functions is highly successful (94% correct classification rate) even when common river-borne taxa are excluded from the analysis.

When applied to buried marsh deposits (ca. 2,000 yr B.P.) classification results from both techniques generally agree indicating that  $\delta^{13}\text{C}$  values are not significantly shifted by diagenetic processes in the sediments. Comparison of information provided by both



techniques, however, also demonstrates that important analogues (i.e., progradational marshes) are missing from the suite of modern samples.

## INTRODUCTION

Much of coastal Louisiana is faced with a severe land loss problem. Rates in some areas have been reported as high as  $130 \text{ km}^2\text{a}^{-1}$  (Gagliano 1981) and appear to be increasing (Turner et al 1982). A large portion of this land loss is attributed to the submergence of coastal wetlands. The underlying cause of this submergence is natural subsidence of the Mississippi delta, but it is believed that marsh loss rates have been increased by the construction of levees, spoil banks and canals (Cowan et al. 1988, Turner and Rao 1988). Management actions, such as fresh water diversion of sediments are planned in attempts to slow land loss (Mendelssohn et al., 1983).

Man's disturbance of the delta plain has been so extensive (e.g., river levees and river diversion) that it is impossible to measure rates of marsh loss or change under entirely natural conditions. Even if the impact of man's activities could be completely mitigated rapid rates of changes could continue under natural conditions. An understanding of these natural rates of change is important to assess the potential value of any management action. With adequate dating control paleoecological research could shed light on marsh processes which occurred in the absence of man.

Paleoecological research has been limited in coastal marshes and the southeastern United States, as well. Previously, reconstructions of marsh environments in the Mississippi delta plain were made primarily for the purpose of understanding deltaic processes. Coleman (1966) found that paleomarch deposits could be categorized as to salinity zone on the basis of physical and biological properties (including pollen, Foraminifera, diatoms and algal remains). He reported that salt marsh sediment shows little stratification, with the exception of an occasional silt laminae, contains iron nodules and seeds of *Scirpus olneyi* and *Distichlis spicata* (primarily). Brackish marsh sediment is subdivided on the basis of its higher organic matter content, less abundant nodules, wavy laminations and *Scirpus* seeds. The third class he separated was fresh marsh, denoted by

its high organic content, fresh water algal remains and less abundant nodules. Kusters (1989) recently described characteristics of marsh facies. She separated fresh from salt marsh on the basis of its higher organic content, (>35%) less decomposed state, common occurrence of thin clay beds and limited bioturbation. She noted however, that organic-poor (<35%) "incipient" marshes, which accrete under conditions of overbank flooding, may occur under varying salinities, thus varying plant assemblages. Although generally successful in their purposes these classifications provide no information on plant community or species roles in accumulation of these deposits, or their responses to external conditions which initiate or terminate the organic accretion.

The purpose of this dissertation is to develop an approach which could provide more detailed information on plant community structure and use it as a basis for classification of paleomarch deposits. On the basis of pilot studies two tools were chosen for developing more refined classifications of marsh deposits:  $\delta^{13}\text{C}$  analyses and palynological analyses. Carbon-13 has been used for some paleoecological reconstructions, and although its use was suggested by Emery et al. in 1967, it had not been used for paleoecological studies of coastal wetland systems until reevaluated by Chmura et al. (1985). Palynological analyses is a standard technique for paleoecological research, but had not been widely applied for the purpose of reconstruction of coastal wetlands. Application of both techniques first require that signatures be developed for modern environments which will serve as models for subsequent classification. Barataria Basin was chosen as the primary study area for modern analogues because it contains marshes of all salinity zones, has been relatively well-studied and is the site of continuing research which could provide a vegetational data base for comparison with results of  $\delta^{13}\text{C}$  and palynological analyses.

Chapter one describes the  $\delta^{13}\text{C}$  characteristics of modern marsh environments in Barataria Basin and how they can be discriminated. In chapter three the same marsh sites (and often samples) are used to characterized pollen assemblages from each of four vegetation zones. Barataria Basin is now hydrologically isolated, but river flooding may

have been a common occurrence in older marshes. Thus, it was necessary to understand this component in terms of pollen assemblages. This problem was addressed by conducting a seasonal study of pollen carried in Mississippi River water, as reported in chapter two. In chapter four both techniques are applied to buried marsh sediments to compare their descriptive and classification potentials.

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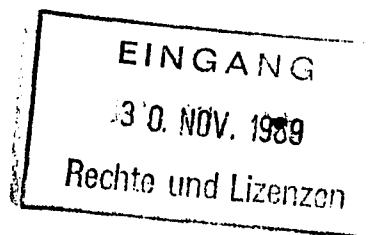


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## An inventory of $^{13}\text{C}$ abundances in coastal wetlands of Louisiana, USA: vegetation and sediments

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**Summary.** Organic carbon-rich sediments from the surface of fresh, intermediate, brackish and salt marshes of coastal Louisiana were sampled and analyzed for their  $^{13}\text{C}$  content. The average  $\delta^{13}\text{C}$  from all sites within each wetland type was  $-27.8\text{‰}$ ,  $-22.1\text{‰}$ ,  $-16.9\text{‰}$ , and  $-16.2\text{‰}$ , for fresh, intermediate, brackish and salt marshes, respectively. Means from the fresh, intermediate and brackish marshes were significantly different at the 0.01 level. A mixing model using measurements of standing crop and  $\delta^{13}\text{C}$  of plant carbon was applied to estimate the contribution of each species to the sedimentary carbon at four of the marsh sites. Sedimentary  $\delta^{13}\text{C}$  values generally reflected that of the dominant species present at each site. Brackish and salt marsh samples, however, showed a negative shift of  $\delta^{13}\text{C}$  with respect to whole plant carbon. We interpret these depleted  $\delta^{13}\text{C}$  values to be the result of more extensive organic matter decomposition and selective preservation of  $^{13}\text{C}$ -depleted refractory components in sediments from saline sites. The results of this study suggest that  $\delta^{13}\text{C}$  composition of sedimentary carbon may offer a valuable tool for distinguishing subtle changes in paleohydrology of wetlands resulting from relative sea level changes.

**Key words:** Wetlands – Stable carbon isotopes – Organic sediment – Salinity gradient – Mississippi delta plain

Stable carbon isotopes have been used to indicate the botanical origin of organic matter in both terrestrial soils (Dzurec et al. 1985, Shonowitz et al. 1986) and wetland sediments (Emery et al. 1967, Nissenbaum and Kaplan 1972, Johnson and Calder 1973, Bein and Horowitz 1986). Most reports focused only on the dominant plant species growing in the area, paying little attention to the complete flora, thus possibly overlooking some important sources of organic carbon. An exception is Dzurec et al. (1985) who report the relative percent cover of vegetation growing at sites of sedimentary carbon sampling.

Discrimination of sedimentary carbon sources is based primarily on the difference in stable  $^{13}\text{C}/^{12}\text{C}$  isotope ratios (expressed as  $\delta^{13}\text{C}$ ) of  $\text{C}_3$  and  $\text{C}_4$  plant species. These two

groups have characteristic  $\delta^{13}\text{C}$  ranges due to differences in fractionation of carbon isotopes during photosynthesis. The  $\text{C}_3$  plants, which utilize only the Calvin cycle in photosynthesis have  $\delta^{13}\text{C}$  values which range between  $-23$  and  $-34\text{‰}$  (Smith and Epstein 1971).  $\text{C}_4$  plants have an additional pathway, the Hatch-Slack pathway, which causes them to discriminate less against  $^{13}\text{C}$  than  $\text{C}_3$  plants do (Vogel 1980; O'Leary 1981). The  $\delta^{13}\text{C}$  range of  $\text{C}_4$  plants is between  $-9$  and  $-17\text{‰}$  (Smith and Epstein 1971).

The extensive coastal wetlands of Louisiana show a gradual salinity gradient from fresh water wetlands in the north to salt marshes bordering the Gulf of Mexico to the south. This salinity gradient is paralleled by a vegetational gradient of  $\text{C}_3$  species (*Panicum hemitomon* and *Sagittaria* spp.) dominating in the fresh marshes to  $\text{C}_4$  species (primarily *Spartina patens* and *S. alterniflora*) dominating in the more saline wetlands. In earlier studies by Chmura et al. (1985) and DeLaune (1986) it was determined that  $\delta^{13}\text{C}$  values of sedimentary carbon of the marshes also reflect this gradient.

The purpose of the present study is to expand on the previous reports of Chmura et al. (1985) and DeLaune (1986) by 1) determining the variability of  $\delta^{13}\text{C}$  values of sedimentary carbon in Louisiana coastal marshes, 2) relating these values to the floral composition at each site, and 3) assessing whether the sedimentary carbon in each marsh can be discriminated on the basis of its  $^{13}\text{C}$  content. All sampling was conducted in the Barataria Basin, an inter-distributary basin which contains wetland systems representative of coastal Louisiana (Fig. 1). The results reported here offer insight as to sources of sedimentary carbon in coastal wetlands, a basis for exploring carbon cycling in local estuarine systems, and a promising tool for assessment of paleoenvironmental changes in the sources of buried sedimentary carbon.

### Study area

The major physiographic regions of the Barataria Basin are shown in Fig. 1. The basin is flanked by levees which were once covered with bottomland hardwood forest, but which are now cleared and utilized for residential areas, roads, industry and agriculture (Conner et al. 1986). Bottomland hardwoods are still present along the lower portions of the levees and in other elevated areas of the basin, such as spoil banks (Conner et al. 1986). Cypress-tupelo swamps are present in the northern portion of the basin

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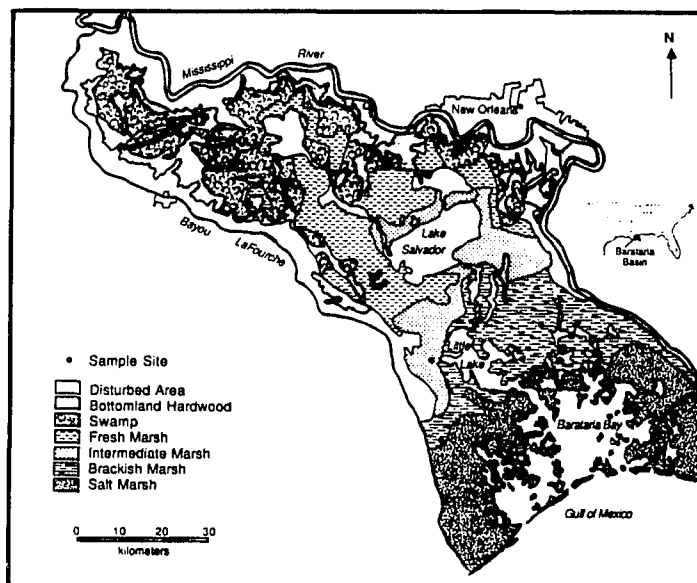


Fig. 1. Map of marsh area and sample locations in the Barataria Basin, Louisiana, USA

and extend southward adjacent to the levees. Herbaceous marshes fill the rest of the basin, around a central drainage system which flows into Barataria Bay and eventually the Gulf of Mexico. Presently the Barataria Basin is an isolated hydrological system, receiving minimal flood waters from either Bayou LaFourche to the west, or the Mississippi River which borders on the east. Natural drainage is primarily in the form of sheet flow over the wetlands, but the exchange of water between different parts of the basin has been accelerated by construction of canals. Canals also serve as channels for various types of discharges from the adjacent developed area (Bahr et al. 1983).

The vegetation association within the Barataria Basin cypress-tupelo swamps has been described by Conner et al. (1986). The primary species are cypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica*) which may occur in pure stands or in mixtures of the two. Ashes and maples may also be present. In addition to the woody understory, many species of floating aquatics and emergent plants can be found on the flooded swamp floor.

The herbaceous marshes are subdivided into fresh, intermediate, brackish and salt zones based primarily on vegetation associations established by Penfound and Hathaway (1938) and Chabreck (1972). These vegetation associations correspond to a salinity gradient of 0.1 to 28.1 ppt (Chabreck 1972) within the basin which causes vegetation diversity to decrease and dominance to increase from the fresh to salt marshes (Gosselink 1984). Although freshwater marshes in the Barataria Basin exist as both emergent and floating, all fresh marshes sampled in this study were floating. The species composition is similar in both (Conner et al. 1986). The vegetation community of the floating marsh, referred to locally as "flotant", was described by Sasser and Gosselink (1984). Although it supports a diverse

plant community including up to 71 species, 85% of the total dry biomass can be accounted for by only five species. Maidencane (*Panicum hemitomon*) comprises 70% of the total aboveground biomass (Sasser and Gosselink 1984). Other important species are the ferns *Thelypteris palustris* and *Osmunda regalis* which account for an additional 10% of the biomass, and vines *Vigna luteola* and *Polygonum sagittatum*, which produce another 5% of the total dry biomass of the plant community (Sasser and Gosselink 1984).

All marshes in the Barataria Basin have considerable spatial variation, but the intermediate marshes seem to be the most varied. In a study of a 90-km<sup>2</sup> site in the basin Sasser et al. (1982) identified six plant associations using statistical clustering techniques and noted even more complex visual patterns with aerial imagery. Local influences of fresh and brackish water, along with slight elevational changes are suggested as the primary causal factors of this variation. Since the relative percent biomass contributed by various species varies considerably from site to site within intermediate marshes (Sasser et al. 1978), any attempt at summarization of this information may be more misleading than valuable. Sasser et al. (1978) noted 25 species in intermediate marshes in a partial survey of the Barataria Basin marshes. Some of the major dominants are considered to be *Spartina patens*, *Phragmites australis*, *Sagittaria falcata* and *Bacopa monnieri* (Gosselink 1984).

A decrease in plant diversity in the brackish marsh is also demonstrated in the report by Sasser et al. (1978), who noted 17 different species in their survey. *Spartina patens* is dominant in this zone. Other common species are *Distichlis spicata*, *Juncus roemerianus*, and *Scirpus* spp. (Conner et al. 1986).

*Spartina alterniflora* is the dominant plant in the salt marshes of the Barataria Basin, often found in extensive



monospecific stands. *Juncus roemerianus*, *Distichlis spicata* and *Spartina patens* may also be found in this zone (Conner et al. 1986).

## Methods

### Clip Plots

Aboveground biomass was measured at four marsh sites by harvesting plant material in quadrats sampled at 20-m spacing along 200-m transect lines. Quadrats were 0.10 m<sup>2</sup> in the intermediate marsh and 0.25 m<sup>2</sup> in all others. Transects ran approximately perpendicular to the nearest water channel (sites could be reached only by boat). Quadrats are numbered sequentially with the site nearest the water access being number one. Isotope data, however, are not available for all quadrats.

All plants, live and dead, within each plot were clipped to ground level and placed in plastic bags. Dead plant material on the surface of each plot was removed along with clipped plants. Only vascular plants were included in the collection. Live plants were sorted by species and oven dried at 65° C to constant weight.

### Sediment sampling

Sediment samples were taken in a cypress swamp, an intermediate marsh, two fresh, four brackish and three salt marsh areas in the Barataria Basin (Fig. 1) by hand-grab, shovel, and hand cores.

In the cypress swamp, samples were taken during the month of July, when low water levels resulted in exposure of much of the swamp floor. Samples were taken from both exposed and flooded areas. A surface cover of litter could be identified on the exposed surface, and was sampled separately from other material. A shovel was used to obtain composite samples from the flooded surface (0–2 cm) and from a 0–6 cm depth in both flooded and exposed areas.

In the clip plot study, sediment samples were taken after plant debris had been cleaned from the plot. Material was obtained by hand to a depth of approximately 3 cm. A hand-corer was used at the remaining 4 sites and subsamples were obtained from the top 3 cm of each.

### Isotope techniques

All sediment samples were stored in plastic bags and refrigerated until processing. Unless specified otherwise, only macrofauna and shell material were removed from sediments. After drying at ≤60° C, sediment subsamples were soaked in 8% HCl overnight to remove carbonates, then centrifuged and rinsed six times with deionized distilled water before drying at 60° C. Processed material was hand-ground to powder. Subsamples, ca 2–7 mg, were combusted with pelletized CuO wire and Ag wire in quartz tubes for a minimum of 9 hr at 900° C according to the method of Sofer (1980). The CO<sub>2</sub> gas was separated from other impurities through cryogenic distillation and analyzed on a Nier-type automated triple collector mass spectrometer of the Stable Isotope Laboratory in the Department of Geology and Geophysics, Louisiana State University, using machine standard NGS (Aharon and Chappell 1986). Accuracy of combustion and mass spectrometry combined was determined by analyses of international standards listed in Table 1. Results are reported in conventional delta (δ) nota-

**Table 1.** Accuracy of standard δ<sup>13</sup>C determinations (relative to PDB standard) over the duration of this study

Standard	Accepted value		Measured value		N
	δ <sup>13</sup> C (‰)	s.d.	δ <sup>13</sup> C (‰)	s.d.	
ANU (sucrose)	–	–	–10.5	±0.2	11
PEF 1 (polyethylene foil)	–31.6*	±0.2	–31.7	±0.2	12
NBS 21 (graphite)	–28.2*	±0.01	–28.2	±0.0	2
NBS 22 (oil)	–29.8*	±0.1	–29.7	±0.1	4

\* Gerstenberger 1982

† Schoell et al. 1983

**Table 2.** δ<sup>13</sup>C values (relative to PDB standard) used to generate predicted ranges for marsh plots based on plant species present

Species	Range of δ <sup>13</sup> C (‰)		Source
	max	min	
<i>Cyperus</i> spp.	–12.1	–15.9	f, g
<i>Distichlis spicata</i>	–12.8	–14.7	b, f
<i>Eleocharis</i> spp.	–25.6	–25.6	i
<i>Juncus roemerianus</i>	–22.8	–24.2	c, d
<i>Leersia oryzoides</i>	–27.5	–27.5	h
<i>Panicum hemitomon</i>	–25.2	–27.5	e, a
<i>Sagittaria</i> spp.	–25.7	–25.7	a
<i>Setaria</i> spp.	–13.4	–14.4	h
<i>Scirpus</i> spp.	–28.7	–30.5	h
<i>Spartina alterniflora</i>	–12.1	–13.6	c
<i>Spartina patens</i>	–11.7	–13.6	a, h

\* Chmura and Aharon, unpublished values; † Bjorkman and Gauhl (1969); ‡ Haines (1976b); § Johnson and Calder (1973); ¶ Smith and Brown (1973); † Smith and Epstein (1971); \* Troughton et al. (1974); † Emery et al. (1967); † Sternberg et al. (1984)

tion in per mil relative to the international standard PDB according to Craig (1957).

### Predictive model

Predicted values for each marsh plot were obtained by application of a simple mixing model based on the assumption that sources of sediment carbon are autochthonous and contributed in direct proportion to the aboveground productivity of each species present:

$$\delta^{13}C_{\text{plot}} = \frac{\sum_{i=1}^n (\% \text{biomass}_i) (\delta^{13}C_i)}{\sum_{i=1}^n \% \text{biomass}_i}$$

where *i* = each species found in plot.

Values for δ<sup>13</sup>C of wetland species were obtained from published reports and some direct measurements (Table 2). Where a range of values exists, both minimum and maximums were used to establish a range for the sediment. Only those species which comprised greater than 1% of the biomass in at least one quadrat of a marsh transect were included in the calculation. For those species for which no value could be obtained the range reported for the genus was used. This broad estimate should increase the probability that the model predictions encompass the actual value for the species.

**Table 3.** Biomass (percent) by species in relation to sediment  $\delta^{13}\text{C}$  values (relative to PDB standard) of 0.25 m<sup>2</sup> plots along a freshwater marsh transect (Only those contributing greater than 1% biomass in any one plot are listed)

Species	Plot							
	1	2	4	5	6	7	8	10
% Biomass								
<i>Panicum hemitomon</i>	64.8	80.9	63.0	84.5	87.2	57.1	71.9	91.1
<i>Solidago</i> sp.	0.2	3.7	21.2		4.6	16.8	15.2	0.9
<i>Thelypteris palustris</i>		6.8	8.3	0.4	1.6	5.3	3.6	3.2
<i>Vigna luteola</i>	5.4	0.2	3.4	6.3	3.6	1.4	1.5	0.7
<i>Sacciolepis striata</i>	25.0							
<i>Leersia oryzoides</i>	0.7	5.7	0.5	6.9	1.2	0.2		3.5
<i>Decodon verticillatus</i>		0.4	1.4			5.2	3.3	
<i>Eleocharis rostellata</i>			0.8	1.9	0.4	3.4	0.2	
<i>Sagittaria latifolia</i>		1.4	0.0*			4.5	0.2	0.2
<i>Hypericum walteri</i>						1.5	2.6	
<i>Eupatorium capillifolium</i>						2.3	1.0	
<i>Acrida tamaracina</i>	2.5							
$\delta^{13}\text{C}$ (‰)								
Measured in sediment	-28.4	-28.0	-28.4	-28.0	-27.9	-28.3	-27.4	-27.8
Predicted from plant C								
high estimate	-25.7	-25.4	-25.2	-25.4	-25.3	-25.3	-25.2	-25.3
low estimate	-27.4	-27.5	-27.5	-27.5	-27.5	-27.3	-27.5	-27.5

\* Species present, but with negligible mass

## Results

### Fresh Marsh

Percent biomass of each plant species harvested in the fresh marsh and the corresponding  $\delta^{13}\text{C}$  value for sediments from each quadrat are reported in Table 3. Vegetation was most diverse at the fresh marsh site, with a total of 22 species represented. The number of species found within an individual plot, however, ranged from 8 to 17. Only three species were found in all plots; *Panicum hemitomon*, a perennial grass, contributed greater than 57% of the aboveground biomass in each; *Vigna luteola*, which contributed 0.2 to 6.3%; and *Polygonum sagittatum* which contributed less than 1%. The latter two species are vines which grew over most of the other vegetation in the plots and may not actually have been rooted within a plot. Measurements of carbon isotope content of sediments for each quadrat in the fresh marsh site are compared to predicted values in Fig. 2. The overall measured  $\delta^{13}\text{C}$  variability of fresh marsh sedi-

ments had the narrowest range of all marsh zones and did not exceed 1‰. This range of -28.4 to -27.4‰ falls just below that of *Panicum hemitomon* and generally, slightly below the predicted range.

### Intermediate marsh

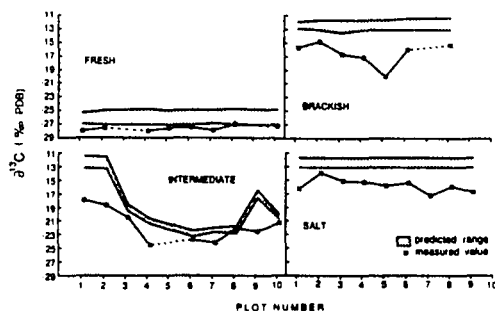
In the intermediate marsh fifteen species were harvested (Table 4). *Spartina patens* and *Eleocharis macrostachya* were the only species common to all plots and generally codominant. Aboveground biomass of *Spartina patens* ranged from 11.7 to 99% and that of *Eleocharis macrostachya*, 1.1 to 59%. Sediments in the intermediate marsh had the broadest range of  $\delta^{13}\text{C}$  values (Fig. 2) of the four herbaceous marshes. Model predictions were not as close to empirical measurements as in the fresh marsh, but did show the same trend, i.e., empirical values were more depleted than predicted solely on the basis of plant carbon.

### Brackish marsh

Plots in the brackish marsh contained only three grass species, all  $\text{C}_4$  plants (Table 5). *Spartina alterniflora* contributed most of the biomass in all plots, as there was relatively low representation by the other grasses. *Spartina patens* and *Distichlis spicata*. The measured sedimentary carbon showed considerably more variation in  $^{13}\text{C}$  content than would be expected from solely autochthonous sources, and greater depletion of  $^{13}\text{C}$  than predicted from plant carbon sources growing at the site (Fig. 2).

### Salt marsh

As is commonly the case in Louisiana salt marshes, *Spartina alterniflora* was the only plant growing in the salt marsh study area (Table 6). Sedimentary carbon in the salt marsh plots showed a similar relationship between empirical and predicted isotope contents as in the brackish marsh (Fig. 2).



**Fig. 2.** Measured and predicted carbon isotope ratios for sediment samples from clip plot study

**Table 4.** Biomass (percent) by species in relation to sediment  $\delta^{13}\text{C}$  values (relative to PDB standard) of 0.1 m<sup>2</sup> plots along an intermediate marsh transect (Only those species contributing greater than 1% biomass are listed)

Species	Plot									
	1	2	3	4	6	7	8	9	10	
% Biomass										
<i>Spartina patens</i>	98.9	81.6	37.4	30.6	11.7	24.9	16.1	49.6	35.5	
<i>Eleocharis macrostachya</i>	1.0	0.4	51.8	59.6	50.7	56.9	31.5	35.7	54.0	
<i>Scirpus olneyi</i>			0.2	4.0	18.3	11.9	7.7		3.5	
<i>Juncus roemerianus</i>							42.6			
<i>Bacopa monnieri</i>					3.8	0.9				5.6
<i>Distichlis spicata</i>	0.1	17.1	10.3							
<i>Setaria geniculata</i>		0.9	0.2	1.7	8.3		1.6	13.6		
<i>Eleocharis cellulosa</i>					5.5	2.1				
<i>Aster tenuifolius</i>				4.1	1.7					
<i>Cyperus polystachus</i>								1.1		
<i>Lythrum lineare</i>						3.4				
$\delta^{13}\text{C}$ (‰)										
Measured in sediment	-18.4	-19.2	-21.0	-25.0	-24.2	-24.6	-22.5	-23.0		21.7
Predicted from plant C										
high estimate	-11.9	-12.0	-19.1	-21.1	-22.8	-22.4	-22.2	-16.9	-20.5	
low estimate	-13.7	-13.8	-20.0	-21.8	-23.7	-23.1	-23.3	-18.0	-21.2	

**Table 5.** Biomass (percent) by species in relation to sediment  $\delta^{13}\text{C}$  values (relative to PDB standard) of 0.25m<sup>2</sup> plots along a brackish marsh transect

Species	Plot							
	1	2	3	4	5	6	8	
% Biomass								
<i>Spartina alterniflora</i>	69.9	100.0	100.0	100.0	100.0	61.5	16.8	
<i>Spartina patens</i>	3.3					38.5	83.2	
<i>Distichlis spicata</i>	26.8							
$\delta^{13}\text{C}$ (‰)								
Measured in sediment	-16.1	-15.3	-17.1	-17.6	-20.4	-16.5	-15.8	
Predicted from plant C								
high estimate	-12.3	-12.1	-12.1	-12.1	-12.1	-11.9	-11.8	
low estimate	-13.4	-13.6	-14.0	-13.6	-13.6	-13.6	-13.6	

**Table 6.** Biomass (percent) by species in relation to sediment  $\delta^{13}\text{C}$  values (relative to PDB standard) of 0.25 m<sup>2</sup> plots along a salt marsh transect

Species	Plot								
	1	2	3	4	5	6	7	8	9
% Biomass									
<i>Spartina alterniflora</i>	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
$\delta^{13}\text{C}$ (‰)									
Measured in sediment	-16.7	-14.4	-15.6	-15.7	-16.3	-15.8	-17.7	-16.4	-17.2
Predicted from plant C									
high estimate	-12.1	-12.1	-12.1	-12.1	-12.1	-12.1	-12.1	-12.1	-12.1
low estimate	-13.6	-13.6	-13.6	-13.6	-13.6	-13.6	-13.6	-13.6	-13.6

#### Cypress swamp

Samples from the cypress swamp provide information regarding variation within microenvironments of this system, but no data are available to enable a comparison of vegeta-

tion and its biomass to the isotopic content of the sediments. The  $^{13}\text{C}$  content of all sedimentary carbon samples vary less than 0.3‰ from the isotopic content of the plant litter on the exposed swamp surface (Table 7).

The range and means of the  $\delta^{13}\text{C}$  of sedimentary carbon

Table 7. Variation of  $\delta^{13}\text{C}$  (relative to PDB standard) within sediments of a cypress swamp

Surface condition	Depth (cm)	$\delta^{13}\text{C}$ (‰)
Exposed	litter	-27.7
Exposed	0-6	-27.2
Flooded	0-2	-27.6
Flooded	0-6	-27.4

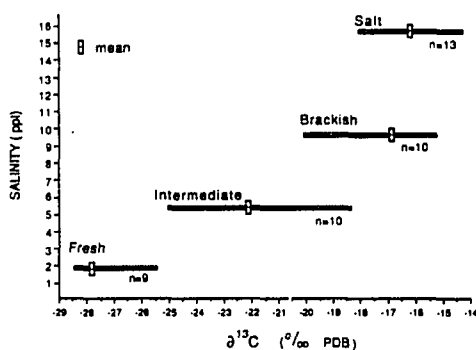


Fig. 3. Range and mean of sedimentary  $\delta^{13}\text{C}$  for fresh, brackish and salt marshes. Water salinities are those reported by Chabreck (1972)

from all marsh sites plotted against water salinity are shown in Fig. 3. Means were statistically compared using the method of least significant differences (LSD) with a protected *F* at the 0.01 level (Little and Hills 1978). Fresh and intermediate marshes have distinctive ranges and significantly different means. Although there is overlap in their ranges, the means of intermediate and brackish marshes are also significantly different. The mean  $\delta^{13}\text{C}$  of salt marsh sediments is 0.4‰ more enriched than that of brackish sediments, but they are statistically indistinguishable.

#### Discussion

A comparison of the four marsh salinity zones of coastal Louisiana indicates that  $\delta^{13}\text{C}$  values of sedimentary carbon are primarily derived from plant carbon of the local dominant marsh vegetation. This relationship is particularly evident in the fresh marsh where sedimentary carbon varies less than 1‰ from reported  $\delta^{13}\text{C}$  values for *Panicum hemitomon*, the dominant plant in this marsh. The relationship of sedimentary carbon to plant carbon appears to be more irregular in the intermediate marsh, with some  $\delta^{13}\text{C}$  values more depleted than the prediction based on the local plant carbon source. This discrepancy may be a result of an underestimation of the production of *Eleocharis* ( $\delta^{13}\text{C} = -25.6$ ‰, Table 2) in these plots. The single measurement of standing crop utilized in this study may not be an adequate representation of the total yearly production of this plant. *Eleocharis* is a perennial evergreen sedge with basal leaves which may be easily incorporated into the sediment and may, over a year's time, have contributed considerably more biomass than is indicated in the standing crop measurements included in this study. Since *Eleocharis* is a  $\text{C}_3$

plant, its yearly contribution to sedimentary carbon may explain the discrepancy between measured and predicted  $\delta^{13}\text{C}$  values (Fig. 2).

In the brackish and salt marshes it is apparent that additional factors play an important role in determining the composite  $\delta^{13}\text{C}$  of the sediment as there is a systematic negative shift of sedimentary  $\delta^{13}\text{C}$  values from that of plant carbon. A similar shift in sedimentary  $\delta^{13}\text{C}$  values in salt marshes has been discussed by Haines (1976a), Peterson et al. (1980), Ember et al. (1987) and DeLaune (1986). These shifts in  $\delta^{13}\text{C}$  values may be due either to undocumented carbon sources, or to fractionation of plant carbon in the sediment during early diagenesis. These alternatives are briefly evaluated below.

There are three potential sources of carbon in brackish and salt marshes which have not been included in the present study: (i) benthic algae on the marsh surface, (ii) allochthonous sources in the form of particulate organic carbon from upper Barataria Basin, phytoplankton or resuspended material from the local bay bottom, and (iii) chemosynthetic bacteria. Haines (1976a, b) suggested that production of benthic algae may supplement inputs of vascular plant carbon in the Massachusetts salt marsh she studied. Benthic algae production in coastal Louisiana has not been extensively studied. Its contribution to sedimentary carbon can be roughly estimated from a gas chamber study by Gosselink et al. (1977) who report that 4 to 11% of the  $\text{CO}_2$  fixed was due to photosynthetic production of algae. To test this hypothesis we can recalculate the predicted values for  $\delta^{13}\text{C}$  of sedimentary carbon using the highest production value (11%) of Gosselink et al. (1977), and the most depleted  $\delta^{13}\text{C}$  value ( $-17.9$ ‰) for benthic algae reported by Haines (1976b). The new  $\delta^{13}\text{C}$  estimate for salt marsh sites, based on both vascular plant and algal carbon, is  $-14.1$ ‰ - a value still more enriched than any measured value. Thus, production of benthic algae alone can not be invoked as a sole explanation for the  $\delta^{13}\text{C}$  shifts.

As all the allochthonous sources of sedimentary carbon have depleted  $\delta^{13}\text{C}$  values, they may also be a factor contributing to the systematic shift in  $\delta^{13}\text{C}$  values with these marsh salinity zones. Since Barataria Basin is hydrologically isolated, allochthonous organic matter is expected to be derived primarily from sources within the basin and transport of organic material is likely to be in the direction of the drainage system, down-basin. In the fresh marsh, sources of allochthonous material will be limited to cypress swamps, bottomland hardwoods and levees. These carbon sources generally will have  $^{13}\text{C}$  contents derived from  $\text{C}_3$  vegetation, similar to that of the fresh marsh vegetation. Since the intermediate marsh is down drainage from these systems, it is possible that transported organic matter will be depleted in  $^{13}\text{C}$  relative to the autochthonous organic matter. The incorporation of this transported organic matter would deplete the  $^{13}\text{C}$  content of the composite sedimentary carbon. This "dilution" effect would be even more noticeable in brackish and salt marshes where plant carbon has  $\delta^{13}\text{C}$  values considerably more enriched than the plant carbon which might be transported from fresh or intermediate marshes.

DeLaune (1986) reported a value of  $-22.8$ ‰ for organic material from the bottom of Caminada Bay (a western branch of Barataria Bay, Fig. 1). This value falls in the range of that which would be expected for carbon transported from the upper Basin, or particulate carbon in Mis-

Mississippi River discharges (Shultz and Calder 1976). Feijtel et al. (1985), however, calculated that the carbon flow between Barataria Basin and the Gulf of Mexico is primarily export from tidal saltwater marshes of the lower Basin, thus confirming that any allochthonous contribution to brackish and salt marshes must originate within the Basin.

Peterson et al. (1980) suggested that an important factor contributing to the negative shift of sedimentary  $\delta^{13}\text{C}$  is the contribution of carbon from sulfur-reducing bacteria in anaerobic sediments of the marsh, but they have not reported any  $\delta^{13}\text{C}$  for these bacteria. This hypothesis has been suggested because the carbon source for these microbes is interstitial  $\text{CO}_2$  which may be relatively depleted in  $\delta^{13}\text{C}$  (Whelan 1974, Claypool and Kaplan 1974), thus depleting the composite sedimentary  $^{13}\text{C}$  content.

We believe that decomposition has played the greatest role in causing sedimentary carbon to be depleted in  $^{13}\text{C}$  relative to predicted values based on whole plant carbon. It can be safely assumed that nearly all the dead organic matter sampled in the sediments of the clip plots was older than one year, as surface litter was removed from each plot prior to sediment sampling. All autochthonous organic matter must have been a combination of older litter which had been incorporated into the substrate and the live root material present within the surface 3 cm. Marsh plant litter can lose 60 to 90% of its original weight within a year's time (Valiela et al. 1982). This initial weight loss consists primarily of proteins, carbohydrates, hemi-cellulose and cellulose since these are more readily decomposed than lignins and lipids (Tenney and Waksman 1930). Sedimentary carbon greater than one year old therefore reflects the isotopic content of the more refractory material, which is depleted in  $^{13}\text{C}$  with respect to other organic components and whole organisms (Deines 1980, Huc 1980). The  $\delta^{13}\text{C}$  of *Spartina alterniflora* lignin is  $-16.3\text{‰}$ , 3 to 4‰ more depleted in  $^{13}\text{C}$  relative to the whole plant tissue (Ember et al. 1987), and thus very close to that of the mean empirical value for salt marsh sediments. Thus, with decomposition, a negative shift in the  $\delta^{13}\text{C}$  of the organic should be expected.

Decomposition processes may explain why sediments seem to show a greater shift in  $\delta^{13}\text{C}$  from that of whole plant carbon along the salinity gradient. These differences in the degree of shift among marshes could be due to difference in the rate of decomposition and relative proportions of refractory material in the surface sediment at each site. The pH of marsh surface sediments decreases with the decreasing salinity gradient in the Barataria Basin (Feijtel 1986). Since the low pH of the freshwater marsh would inhibit decomposition in the freshwater sediment (Benner et al. 1985; Kilham and Alexander 1984), it would be expected to contain lower relative percentages of refractory material in sedimentary carbon. Thus, the  $\delta^{13}\text{C}$  of this less decomposed sediment in the fresh marsh would be closer to that of the original whole-plant carbon and with extended decomposition, sedimentary carbon would become increasingly depleted in  $^{13}\text{C}$  relative to whole plant carbon.

Support for our contentions is offered by the observed close relationship of  $\delta^{13}\text{C}$  values of the cypress swamp sediments and surface plant litter (Table 7). The identity of these values is because decomposition of organic components such as proteins and carbohydrates can be relatively rapid in forest litter (Waksman et al. 1928) and only refractory components remained in the litter sampled (mid-sum-

mer). In a similar swamp forest community, the Great Dismal Swamp, Day (1982) found that most of the decomposition occurred within the first year after litter fall. Since surface litter probably underwent little decomposition after incorporation into the sediment the  $\delta^{13}\text{C}$  contents of the two are very similar.

Since marsh salinity zones could be recognized by the  $\delta^{13}\text{C}$  content of their sedimentary carbon (Fig. 3), with one qualification below, stable carbon isotope analyses can be a valuable method for determining the origin of buried marsh sediments. In turn, identification of temporal shifts in the stratigraphic boundary between fresh and saline marshes may offer a valuable indicator of paleosea levels during transgressive or regressive phases.

Utilization of the carbon isotope method for paleoenvironmental study of wetland may, however, be complicated by the effects of early diagenesis as documented in our study. Although DeLaune (1986) concluded that at shallow depths  $^{13}\text{C}$ -fractionation is insignificant, it remains to be proven to what age and depth the sedimentary carbon retains its signature.

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## CHAPTER 2. POLLEN IN THE LOWER MISSISSIPPI RIVER<sup>1</sup>

### **Abstract**

In this paper we report on a 7-month study (February to August 1987) of pollen transported by the Mississippi River. Results are presented for samples collected at Pointe a la Hache, Louisiana. Pollen concentrations range from 657 grains l<sup>-1</sup> in August to 8,479 grains l<sup>-1</sup> in April and are positively correlated to suspended sediment concentrations ( $r=0.81$ ). Using this relationship it is calculated that ca.  $1 \times 10^{19}$  grains of pollen and spores are discharged annually into the Gulf of Mexico, a significant source of pollen to marine sediments there. The pollen assemblage appears to reflect pollen transported from sources throughout the Mississippi River drainage system, but some exclusively northern taxa are present at very low concentrations. The relative abundance of most components varies temporally in relation to factors of pollen production, runoff in the drainage area, and characteristics of river flow. High concentrations of indeterminate grains, corresponding to river flood stages, are assumed to be due to resuspension of river deposits and may be used as an indicator of fluvial transport.

### **Introduction**

Fluvially transported pollen is a significant source of pollen in alluvial deposits (Fall, 1987; Hall, 1985) and may be a major source in near-shore marine sediments (Heusser, 1985; Cross et al., 1966; Stanley, 1965; Muller, 1959). Increased concentrations of pollen in marine sediments have been attributed to transport by rivers debouching into the local basin, resulting in increased deposition of pollen and sediments, or even introduction of the pollen load into marine currents (Cross et al., 1966; Stanley, 1965;

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Muller, 1959). Groot and Groot (1966), however, estimated that the fluvial pollen load contributed to the northwestern Atlantic was less than that contributed by aerial sources. If fluvially transported pollen is a significant component of a pollen assemblage its interpretation necessitates an understanding of the characteristics of the spectra of the transported pollen.

Few researchers have attempted to document the pollen load carried by fluvial systems. Exceptions are studies of the Volga River (Federova, 1952), a small Yorkshire stream (Peck, 1972), a New Forest stream (Brown, 1985), Wilton Creek, Ontario (Crowder and Cuddy, 1972) and Groot's (1966) study of the Delaware River estuary. Groot (1966), sampling during the month of August, found that the pollen spectra of the Delaware River estuary represented both local and regional vegetation, including taxa whose distribution is limited to regions 200 km upstream. Brush and DeFries (1981), who studied sediments of the Potomac Estuary, concluded that pollen grains were not transported great distances and that they were differentially dispersed before being deposited. Crowder and Cuddy (1972) and Peck (1972) found temporal variability in their long-term studies and concluded that fluvial transport was significant in the pollen budgets of the lakes in their studies.

In this paper we report on a 7-month study of pollen transported by the Mississippi River which drains an area of 3,344,560 km<sup>2</sup>, the third largest catchment in the world. Our objectives are: to characterize the pollen assemblage suspended in the river, determine its seasonal variability, the sources of the pollen load, and how the assemblage would be reflected in related fluvial and marine deposits. For purposes of this report we present data from samples collected at the Pointe a la Hache ferry landing (Fig.1). Pointe a la Hache is located the furthest downstream of all public river crossing sites.

Since 1927 there has been an approximately 60% decrease in the suspended sediment load of the Mississippi River, due primarily to reservoir, flood control and bank



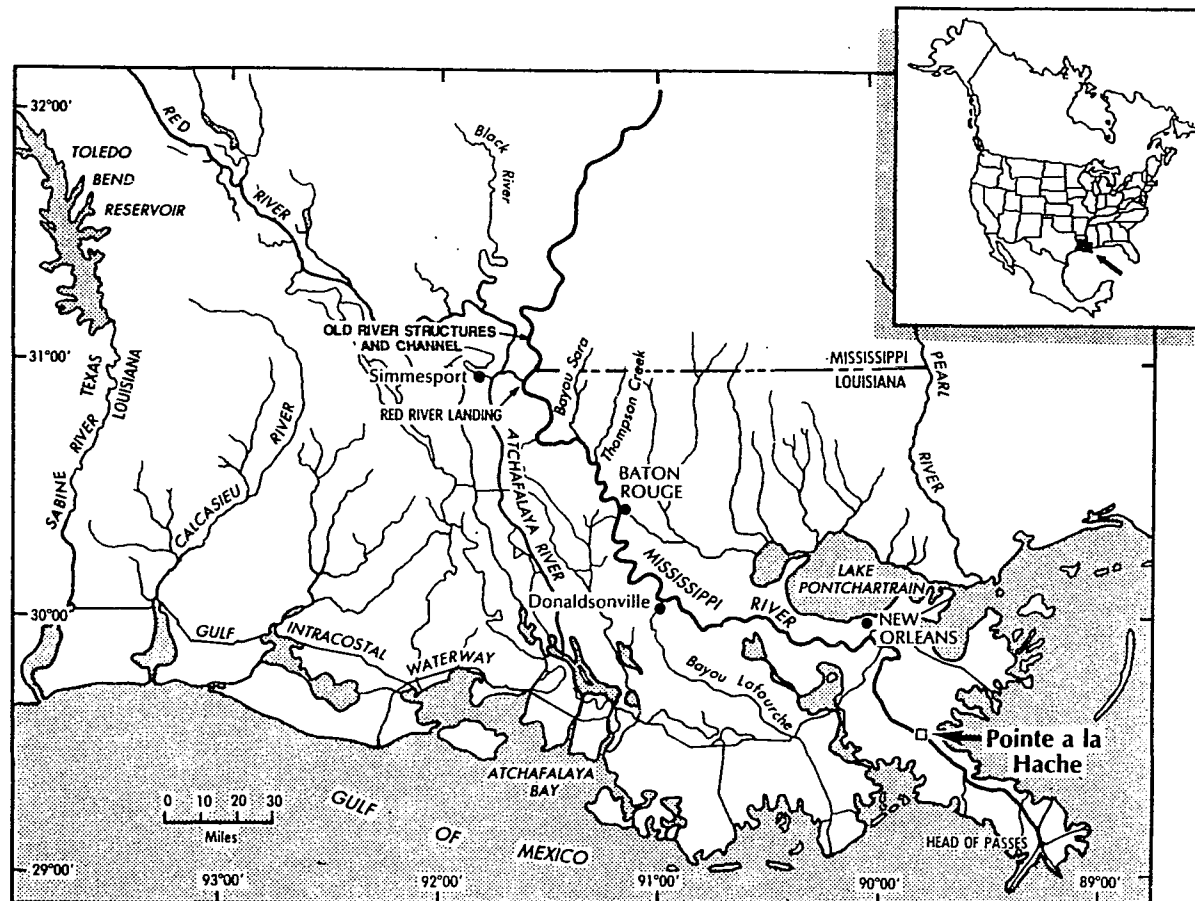


Fig.1. Map of sample site and tributaries on the lower Mississippi River in Louisiana.

protection works along major tributaries and the main trunk of the river (Kesel, 1988; Keown et al., 1981). Table I lists proportions of sediment yields from the component basins. Since the recent completion of the Old River diversion structure, 30% of the flow of the Mississippi River has been diverted to the Atchafalaya River, which also receives the flow of the Red River. Annual sediment discharge of the Mississippi is  $6.21 \times 10^{11}$  kg. Annual water discharge averages  $15,360 \text{ m}^3 \text{sec}^{-1}$  and ranges from an average minimum of  $2,830 \text{ m}^3 \text{sec}^{-1}$  to an average maximum of  $57,900 \text{ m}^3 \text{sec}^{-1}$ . Highest flows usually occur from February to May while the lowest flows are in September, October, and November (Keown et al., 1981).

## Methods

Mississippi River water samples were taken at Pointe a la Hache (Fig.1) on February 16, March 9, April 13, May 11, June 8, and August 10, 1987 by the Water Pollution Control Division, Office of Water Resources, Louisiana Department of Environmental Quality (DEQ). Samples were taken at a depth of 1 m from both river banks. Total suspended solids and dissolved solids were measured by the DEQ Water Pollution Control Division laboratory.

Pollen was concentrated from 0.4 to 1.1 liter subsamples to which exotic *Lycopodium* spores (ca. 12,100 grains per tablet) had been added (Stockmarr, 1971). During the first sampling period, February, a number of methods were explored for reducing water volumes: boiling, centrifuging, filtering through Nitex cloth and acetate filters. Centrifuging was chosen as the method most suitable to the turbidity and volume of samples. Pollen concentration was not estimated for the February water sample. All samples were processed with conventional HF and acetolysis treatments (Faegri and Iversen, 1975), stained, and mounted in silicone oil. In most cases low pollen densities necessitated that counts be made through first scanning at 200x magnification prior to identification of individual grains at 400x magnification. A minimum of 250 grains was

TABLE I

Proportion of total estimated annual sediment yield to the  
Mississippi River Basin (Keown, 1986)

Basin	%
Arkansas-White Rivers	6
Missouri River	35
Ohio River	32
Upper Mississippi River	22
Lower Mississippi River	5
Western Tennessee Subbasin	<1

counted. Pollen concentration was calculated with the formula:  $\text{Concentration} = (\text{total count} \times 12,100) / (\text{Exotic counted} \times \text{sample volume})$ .

All pollen with characteristic Cupressaceae-type split were counted as Taxodiaceae-Cupressaceae-Taxaceae type (TCT), recognizing the potential contribution of *Taxodium distichum*, a local and common member of Taxodiaceae which may split in a similar fashion. Those grains with visible exit papillae (Kapp, 1969), however, were counted separately as *Taxodium*. *Ambrosia* and *Artemisia* pollen were collectively termed short-spine Compositae, but most of such grains counted were *Ambrosia* type.

Regression analysis of pollen and sediment concentrations was performed after subtracting the contribution of the pollen and spores component of the total solids concentration. For each sample the mass of this component was determined by multiplying the pollen concentration by an assumed average grain mass of  $4.8 \times 10^{-6}$  mg, based on measurements reported by Brush and Brush (1972). The calculated mass of pollen and spores in each sample was small, less than  $0.07 \text{ mg l}^{-1}$  at the highest grain concentration.

## Results and Discussion

At Pointe a la Hache the concentration of pollen and spores was lowest in August and highest in April, ranging from 657 to 8,479 grains  $\text{l}^{-1}$ . The concentration of total solids shows the same trend, ranging from 192  $\text{mg l}^{-1}$  in August to 552  $\text{mg l}^{-1}$  in April (Fig. 2).

Pollen concentration and suspended sediment concentrations are highly correlated ( $r=0.81$ ,  $P<0.001$ ). Pollen transported as suspended load would be expected to fall out with the fine silt and clay fraction of the river plume, particularly in the area of the delta front and prodelta which are major sites of deposition of silt and clay (Coleman, 1988). Darrell and Hart (1970) counted pollen in prodelta sediments and found concentrations

MISSISSIPPI RIVER, POINTE A LA HACHE, LOUISIANA, USA - 1987

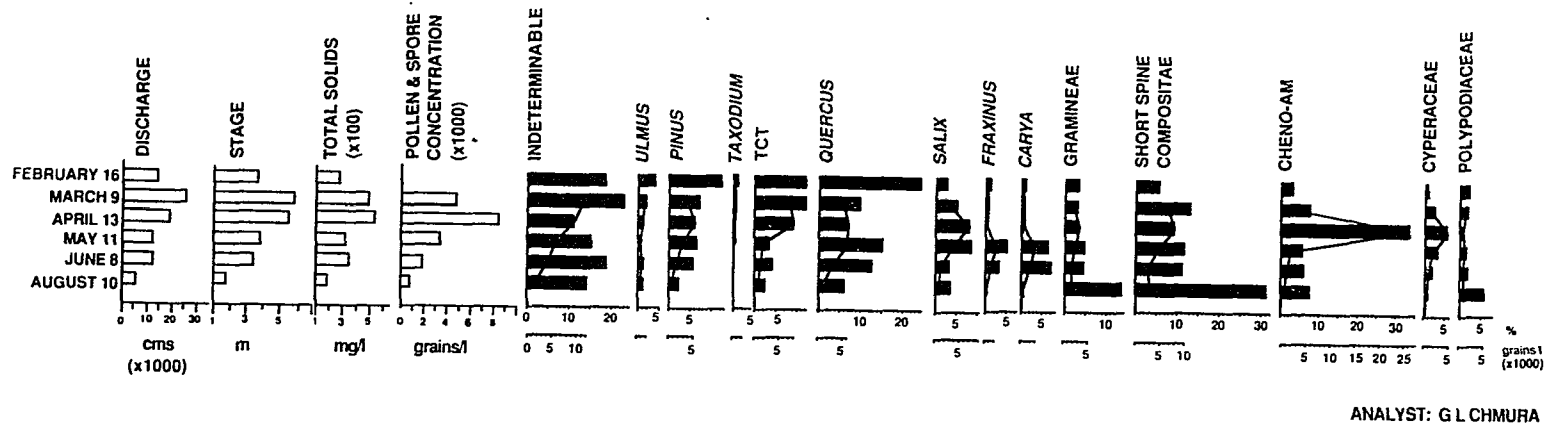


Fig.2. Monthly pollen assemblage with corresponding river stage<sup>1</sup> and total solids concentrations<sup>2</sup> at Pointe a la Hache, Louisiana. River discharge<sup>1</sup> measured at Tarbert Landing, Mississippi on dates indicated, except for February sample, which was taken on February 17. Pollen data are averages of samples from both banks. Note the two scales at the bottom. The upper scale is for pollen percentages (solid bars) and the lower one is for pollen concentration values (curves). Pollen concentration data for February are unavailable.

<sup>1</sup> unpublished preliminary data, U.S. Army Corps of Engineers, New Orleans District; <sup>2</sup> unpublished data Louisiana Department of Environmental Quality Water Quality Laboratory

from 8 to  $20 \times 10^3$  grains  $g^{-1}$ , a range which brackets our calculated average of  $14 \times 10^3$  grains  $g^{-1}$  suspended sediment.

Table II lists the average relative abundances of the major components of the assemblage over the sampling period. Short-spine Compositae, *Quercus*, Cheno-Am (Chenopodiaceae-Amaranthaceae) and indeterminable grains are the most abundant, all averaging >10% over the study period.

In April the percentage of Cheno-Am types was over 30% of all types counted. This percentage, which is represented by only the east bank sample, is twice as high as the percentage determined from samples at five other sites on the river taken in the same month (Chmura, unpublished data). It is likely that the April Pointe a la Hache assemblage was affected by blooming of weeds on the river bank at this time. Since this phenomena was not detected in any other sample it is believed that, generally, pollen sources from river bank vegetation do not hinder interpretation of the river water assemblages.

The percentage and concentrations of indeterminable grains are high relative to that of individual taxa. The concentration and percent of indeterminable grains, along with discharge and river stage, peak in March. This is in marked contrast to concentrations of total grains, solids and most of the individual taxa, which peak in April. Percentages of individual taxa seldom peak in April, but vary independently throughout the sampling period.

Many of the identifiable components of the pollen assemblage appear to follow a trend related to the blooming period of species represented within the group. To estimate the beginning of flowering seasons we use records of aerial pollen counts from locations within the Mississippi River drainage system. Table III lists the date on which taxa were first noted within samples of aerial pollen, indicating that blooming had occurred within the region. To assure that these dates represented the beginnning of a blooming period

TABLE II

Major components of the Mississippi River pollen assemblage during 1987 at Pointe a la Hache, average of both banks

Taxa	% total sum		grains l <sup>-1</sup>	
	Feb-Aug avg	March	March-Aug <sup>1</sup> avg	March
Indeterminate	17	23	611	2196
TCT	8	14	330	1336
Compositae <sup>2</sup>	13	13	455	1258
<i>Quercus</i>	12	10	369	885
<i>Pinus</i>	7	7	238	668
Cheno-Am	10	7	668	742
<i>Salix</i>	5	5	257	482
Gramineae	5	3	151	298
Cyperaceae	2	2	134	193
Polypodiaceae	2	2	51	165
<i>Carya</i>	3	<1	83	34
<i>Ulmus</i>	2	2	40	165
<i>Fraxinus</i>	2	<1	50	22

<sup>1</sup> Concentration data for the month of February are not available

<sup>2</sup> Short-spine type

TABLE III

Date of which first of repeated appearances are noted in 1987 aerial pollen counts. Blanks indicate that no report is given for that group

	1st report	<i>Ulmus</i>	<i>Pinus</i>	TCT	<i>Quercus</i>	<i>Salix</i>	<i>Fraxinus</i>	Gramineae	<i>Ambrosia</i>
sampling station	----- month or month/day -----								
Billings, MT <sup>1</sup>	1/1	2	4	2			4	4	8
Minneapolis, MN <sup>2</sup>	3/15	3/17						6/4	7/27
Mason City, IA <sup>1</sup>	2/1	2	2	2	3	4	6	5	8
Kalamazoo, MI <sup>1</sup>	1/1	3	5	3	4	4	4	6	8
Rockford, IL <sup>2</sup>	7/6							7/7	7/27
Fort Wayne, IN <sup>2</sup>	3/16		4/2		4/26			5/28	7/28
Kettering, OH <sup>3</sup>	3/25		4/13		4/13			4/10	7/30
Cincinnati, OH <sup>2</sup>	3/31		5/4		4/26			4/19	7/27 <sub>p</sub>
Clayton, MO <sup>4</sup>	1/1	1/9	1/14	1/7	4/1	3/18		4/1	7/13
Cape Girardeau, MO <sup>1</sup>	1/1	2	3	1	3	4	4	4	8
Wichita, KS <sup>2</sup>	3/16							5/12	7/13
Tulsa, OK <sup>2</sup>	3/17		3/17	3/17				3/18	8/9
New Orleans, LA <sup>5</sup>	1/5	2/4	4/2		3/18			3/4	8/31

1 Burge and Chapman, 1988; 2 unpublished data, Multidata, Inc., St. Paul, Minnesota; 3 Regional Air Pollution Control Agency, Dayton, Ohio 4 unpublished data, Environmental Health Laboratories, Department of Community Health and Medical Care, St. Louis County, Missouri; 5 unpublished data, Department of Clinical Immunology, Tulane Medical Center, New Orleans, Louisiana.



"first appearance" dates were considered only as those records followed by additional counts within a week's time, and individual scattered records were ignored.

Representatives of strictly northern taxa, such as *Abies*, *Picea*, *Tsuga* and *Pinus strobus* are virtually absent from the Mississippi water samples, even in months following their blooming period. Such grains were counted, but these were isolated occurrences and never represented more than 1% of the total sum in any one sample. In samples of Mississippi River water collected during April and July near the headwaters of the river in Minneapolis, Minnesota, percentages did not exceed 1% for *Pinus strobus*, 3% for *Picea*, and neither *Tsuga* nor *Abies* were counted (Chmura, unpublished data). Thus the lack of the above does not necessarily suggest a substantial loss or degradation of these types within the Mississippi River. The presence of *Picea*, however, does demonstrate that these grains can be transported the entire 2000 mile length (3,218 km) of the river.

Greater numbers of other pollen types from northern regions do move through the Mississippi River within a single season. One example is *Fraxinus*, which is a major component of southern bottomland hardwood forests (Delcourt et al., 1984; Fowells, 1965), but which is also distributed throughout the upper Mississippi River system. *Fraxinus* blooms in Louisiana in February and March (Brown, 1945), but does not appear in the river assemblage until May, following its appearance in aerial counts in Michigan, Missouri and Montana (Table III). The highest concentration of this taxon does not coincide with maximum sediment and total grain concentrations, suggesting that these peaks are due to production rather than increased runoff.

Additional evidence of a northern component in this assemblage is the distribution of the short-spine Compositae, which primarily reflects *Ambrosia*. This is a short-day plant which blooms earlier at higher latitudes than at lower latitudes in the northern hemisphere. In August the percent *Ambrosia* is twice that of the next highest month and its concentration reaches a secondary maximum. This increase must be due to its July

blooming in northern areas since *Ambrosia* is not noted in aerial assemblages in Louisiana until late August (Table III).

There is evidence in the pollen assemblage of strictly southern taxa, as well. The concentration of *Taxodium distichum* pollen (those with exit papillae visible) peaks in February. This is the first sampling period of the study and follows the peak blooming period of *Taxodium distichum* by two months. The presence of these papillate grains indicates that this peak corresponds to both the recent blooming and limited transport distance which would reduce opportunities for reworking and grain deterioration. It is assumed that *Taxodium* is also a major component of the TCT group during this period.

Other arboreal taxa seem to reflect both local, or southern, and upstream sources of the river's pollen assemblage, depending upon the period sampled. *Ulmus americana* and *Pinus caribaea* bloom in January in Louisiana (Brown, 1945) thus it may be assumed that the February peak of *Ulmus* and *Pinus* is due to a local source. Within the Mississippi River drainage system, however, different species of *Ulmus* have widely different blooming periods with some species blooming in the fall, while *Pinus spp.* continues to bloom through March in Louisiana and as late as April and May in the upper reaches of the drainage system (Brown, 1945; Fowells, 1965). During the remainder of the sampling period both groups probably receive contributions from throughout the system. Abundances of *Quercus* and *Salix* also may reflect input from sources throughout the drainage system, but May percentage peaks seem to follow the later April blooming in northern regions.

A third source of grains in the Mississippi River pollen assemblage is that of river banks and bars eroded during periods of peak flow when hydraulic capacity is highest. Grains from these sources are likely to be the most deteriorated due to sediment abrasion and exposure to aerobic conditions at low river stages (Cushing, 1964). This is the most likely explanation for the coincidence of peak concentrations of indeterminable grains and river discharge. It can be assumed that indeterminable grains have been within the river

system since at least the last period of slack water, perhaps considerably longer. This interpretation supports that of other researchers who concluded that high percentages of reworked grains in stream water (Brown, 1985) and in marine sediments (Heusser, 1985; Stanley 1966a & b) are a result of increased erosion of fluvial deposits.

Resuspended sediments may be a significant source of other components of the river assemblage. In March there is a secondary maximum in the relative percentage of short-spine *Compositae* corresponding to peak discharge and the peak concentration of this group is concurrent with the peak suspended sediment concentration in April. Many of the grains observed in these counts were flattened, worn, abraded and/or had notably thin exines, suggesting that this early concentration is due to increased runoff and resuspension of previously deposited grains, rather than production.

Once pollen is discharged into the Gulf of Mexico, deposition should parallel the distribution of the Mississippi River plume. The plume's movement varies with respect to river discharge, meteorological conditions, and marine currents, and has seasonal variations in its distribution (Dinnell and Wiseman, 1986). Since the river pollen assemblage also changes seasonally, there may be spatial variation in pollen assemblages of local continental shelf sediments, reflecting this dual seasonality. Palynological studies of northern Gulf of Mexico sediments have been limited (Heusser, 1985). Stanley (1966a&b) reported counts from the Sigsbee Deep and Heusser (1985, 1987) from the Orca and Pigmy Basins, all located beyond the shelf edge. Both found high concentrations of reworked grains which were primarily attributed to turbidity currents and base-level lowering of rivers. In the Orca Basin Heusser (1985) found that concentrations of reworked grains decreased in surficial sediments, but still ranged from 20 - 40%. Although Mississippi River water presently has lower concentrations of reworked grains it is possible that it could have been a source for these reworked grains. Prior to 1941 bank caving supplied approximately  $476,000 \text{ m}^3$  of sediment per km of channel to the Lower Mississippi River, but revetment construction has largely eliminated

this sediment source (Kesel, 1988). Thus, concentrations of degraded and reworked grains could have been much higher in the recent past due to greater volumes of resuspended alluvial sediment. There were two other major pollen components in the surficial sediments of the Orca Basin - *Pinus* (~30 - 40 %) and *Quercus* (~20%), both also major components of the Mississippi River pollen assemblage (Table II).

Substituting the average annual suspended sediment discharge of  $6.21 \times 10^{14}$  g (Keown et al., 1981) into the regression equation for the relationship of pollen concentration to suspended sediment concentrations we calculate that in the order of  $1 \times 10^{19}$  grains of pollen and spores are probably discharged annually into the Gulf of Mexico by the main trunk of the Mississippi River. Considering recent stabilization projects this figure may have been even higher in the past. Our present-day value is higher than Groot and Groot's (1966) estimate of  $1.5 \times 10^{17}$  grains  $\text{yr}^{-1}$  for fluvial sources of pollen and the same order of magnitude as their estimate of  $1.5 \times 10^{19}$  grains  $\text{yr}^{-1}$  for aerial pollen sources to the western north Atlantic. As indicated by the work of Muller (1959) and Cross et al. (1966), fluvial sources can be highly significant sources of pollen to sediments of their receiving basin.

Although overbank flooding is prevented along most of the lower Mississippi River, under natural conditions flooding would have occurred during years of exceptionally high river stages, during months of March to June (Keown et al., 1981). Using the March pollen assemblage at Pointe a la Hache and the regression equation for the relationship between pollen concentration and suspended sediment we can estimate the pollen load which would have been introduced to swamps and marshes subject to overbank flooding. The concentration of indeterminable grains is likely to have been significantly increased, followed in order of abundance by TCT, short-spine Compositae, *Quercus*, Cheno-Am, *Pinus*, *Salix*, Gramineae, Cyperaceae, and Polypodiaceae. The high concentration of indeterminable grains is a fortuitous occurrence since it should serve as a signal of

overbank flooding in such wetland deposits to suggest that interpretations should be adjusted to consider the possibility of overabundances of the above taxa.

## **Conclusions**

Longer-term studies should be conducted on both the Mississippi River system and other types of river systems before broad generalizations are made regarding the significance of fluvially transported pollen to marine pollen assemblages. Our conclusions are based on a study of a meandering river system which has been extensively altered by man. Results of this seven month study suggest that:

- 1) Mississippi River water integrates pollen sources from throughout its drainage basin. Sources from river bank vegetation, local and distant vegetation formations can be identified.
- 2) Pollen assemblages have a seasonal signature. Both frequencies and concentrations of pollen types may reflect differential blooming periods in regions throughout the drainage basin.
- 3) Peak flood episodes coincide with peak concentrations and percentages of "indeterminable" and other types of grains from reworked sediments. Deposits from overbank flooding may be recognized by high percentages of these reworked types.

## **Acknowledgements**

We are grateful to the Louisiana Department of Environmental Quality and the DEQ Water Quality Laboratory for their gracious assistance in releasing samples and data. We would like to thank B. Dutcher, W. Black, T. Tschudy and Y. Chapman for providing aerial pollen data; the New Orleans District of the U.S. Army Corps of Engineers for the use of unpublished data, R. Squires for providing Minnesota river samples, and M.L. Eggart for figure preparation.

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CHAPTER 3.  
MODERN POLLEN ASSEMBLAGES IN MARSHES  
OF COASTAL LOUISIANA, USA

INTRODUCTION

Early palynological studies in coastal wetlands addressed geographical questions of broad scope, such as reconstruction of major vegetation formations, paleoclimate and determination of sea level fluctuations (Benninghoff 1942, Deevey 1948, Butler 1949, Potzger 1952, Heusser 1963, Sears 1963, and Newman and Munsart 1968). More recently researchers have used palynological data to determine accretion rates of salt marshes, through identification of historical markers (Mudie and Byrne 1980, Clark and Patterson 1984, Clark et al. 1986, and Heijnis et al. 1987) or concentrations of regional pollen (Heijnis et al. 1987). Only a limited number of studies have been directed at correlating local vegetation communities with surface pollen assemblages and identifying mechanisms of pollen distribution in coastal wetlands (Darrell and Hart 1970, Heusser et al. 1975, Clark and Patterson 1985 and Clark 1986).

Clark and Patterson (1985) described modern pollen distributions along a 600-m transect in a New England salt marsh. They identified regional and local inputs, demonstrating that tidal marsh sections can provide sensitive records of both upland and marsh vegetation histories. On Long Island, New York, Clark (1986) also studied surface pollen distributions along a 600-m back barrier transect which included marsh environments. He concluded that pollen distributions accurately define the extent of local vegetation zones within this environment. Both studies clearly demonstrated that pollen sources must be accounted for before local paleo-environments can be reconstructed.

These studies have prompted a reevaluation of the potential of coastal marshes for palynology-based Quaternary studies. Characteristics of pollen assemblages, however, cannot be directly applied from the coastal marshes of the northeastern United States to

other regions and must be studied from a regional perspective. In coastal Louisiana, particularly, marsh zones are much broader and considerably different from those studied by Clark and Patterson (1985). Palynological studies in wetlands of coastal Louisiana have been limited. Coleman (1966) used physical, faunal and floral properties to distinguish modern sedimentary environments in the Mississippi Delta plain. He found that the representation of regional pollen types increased from fresh to salt marsh zones, while preservation of grains decreased. Representation of local flora was noted, but no pollen counts or diagrams were published and results were judged inconclusive. Darrell and Hart (1970) attempted to distinguish deltaic sub-environments simply on the basis of palynomorph concentration. They concluded that this was not, in general, a useful approach.

Although other methods such as stratigraphy, organic matter content, Foraminifera, radiographs, and Carbon-13 analyses (e.g., Coleman 1966a, Coleman 1966b, Kusters 1989, DeLaune 1986; and Chmura et.al. 1987) are used to distinguish sedimentary environments in the Mississippi Delta plain, none have the same potential as palynological studies. Because palynomorphs occur in large quantities, their distributions can be dealt with numerically (Birks and Birks 1980). If inputs from vegetation within a marsh zone can be identified then this technique could be used to statistically separate marsh environments and develop palynological signatures to enable reconstruction of past marsh environments. Since plant taxa are represented palynologically on various levels, from classes to species, once such reconstruction is made it may be possible to detect more detailed changes in species (or larger taxonomic groups) responses to environmental changes. Another advantage of such study would be to add to source material available for study of Quaternary vegetational history of the southeastern United States. Conventional sources of such material of suitable age, such as bog and lake deposits, are scarce (Delcourt and Delcourt 1985). If regional inputs can be accurately identified, then Mississippi Delta deposits could be utilized for study of Quaternary vegetation history.

The objective of this study is to determine if palynological analysis is a practical tool for study of Louisiana coastal marshes. Sources and distributions of palynomorphs along a 108-km salinity gradient in coastal wetlands of Louisiana are identified. Mechanisms important in the dispersal of palynomorphs along this gradient are then evaluated on the basis of their occurrence and abundance. Finally, the assemblage of palynomorphs within each marsh type is characterized qualitatively and quantitatively through application of discriminant analysis. The study site is Barataria Basin, an estuarine system with two advantages for palynological study. First, the vegetational environments have been relatively well-studied and documented in recent years. Secondly, it is isolated from any major fluvial source of palynomorphs.

#### STUDY AREA

In southern Louisiana the Gulf coastal plain is bisected by the Mississippi alluvial valley (Fig. 1). The Gulf coastal plain is generally characterized by loblolly-shortleaf pine and longleaf-slash pine forest associations (Fig. 2; Delcourt et al. 1981). The Mississippi alluvial valley contains the continually diminishing bottomland hardwoods and cypress-tupelo swamp forest associations. Extensive harvesting of cypress has nearly removed this component so that regions which once supported cypress swamp forests are now dominated by water tupelo and other species (Conner and Sasser 1985). Upland regions of Louisiana are further subdivided by Newton (1972) who lists components of eight forest regions in addition to the prairie and marsh regions (Fig. 3).

The study sites lie within Barataria Basin (Fig. 4), which is presently an isolated hydrological system within the Mississippi Delta plain. It receives minimal flood waters from either Bayou LaFourche to the west or the Mississippi River which borders on the east. Natural drainage is primarily in the form of sheet flow over the wetlands, but the exchange of water between different parts of the basin has been accelerated by construction of canals. Canals also serve as channels for various types of discharges

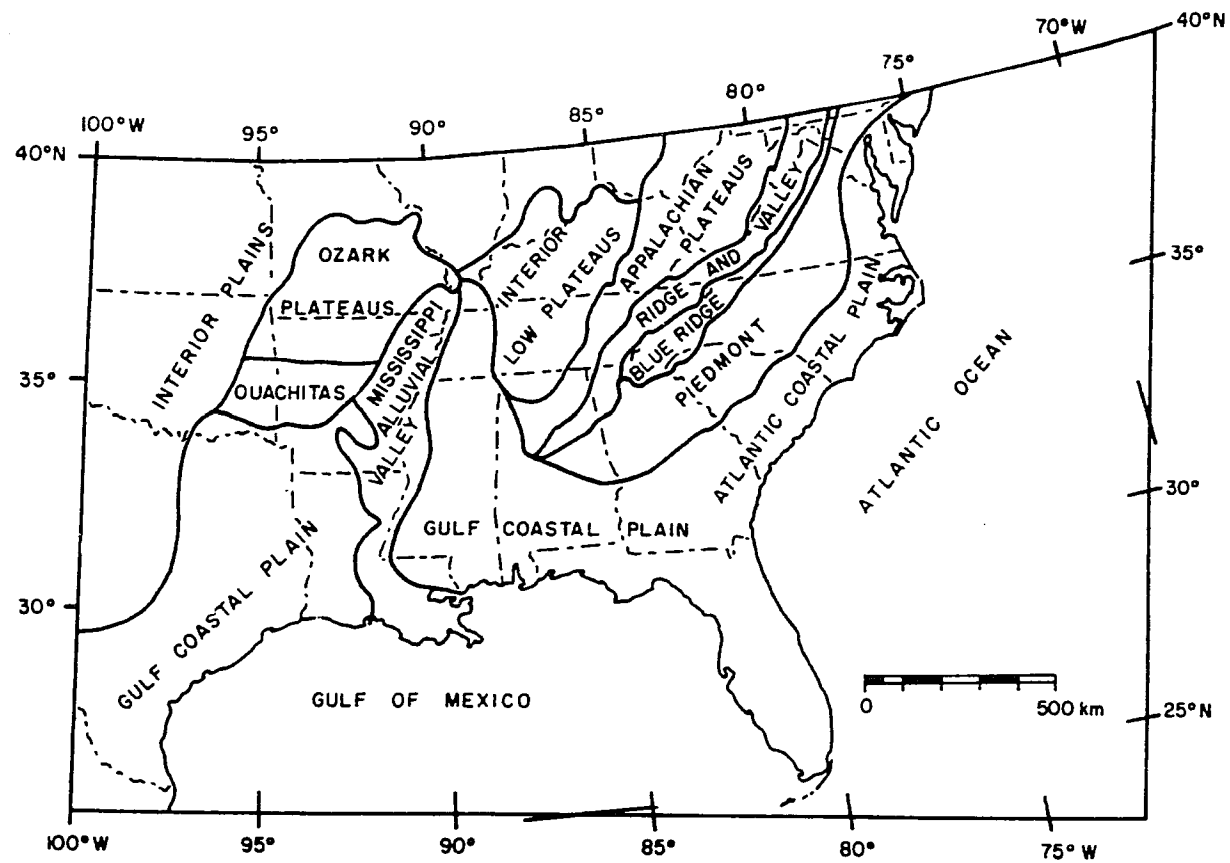


FIG. 1. Physiographic regions of the southeastern U.S. (from Delcourt and Delcourt, 1985).

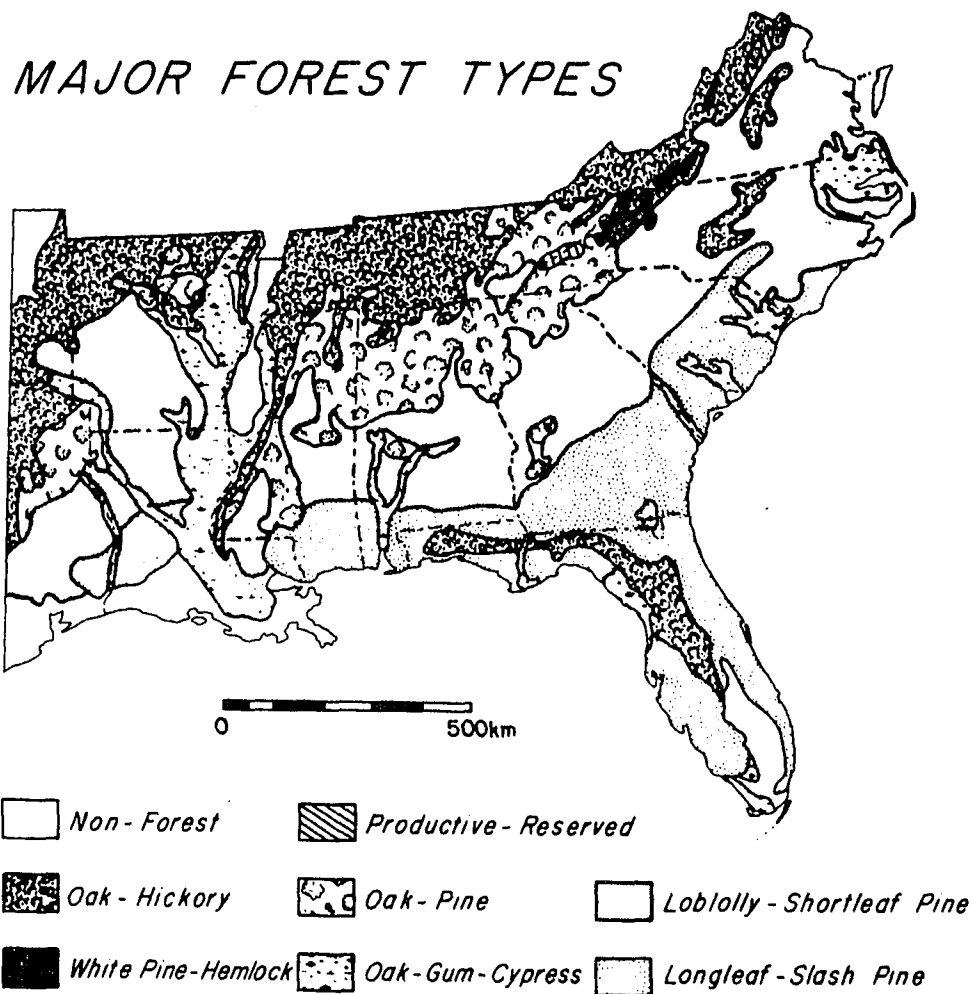


FIG. 2. Major forest regions of the southeastern U.S. (from Delcourt et al., 1981; redrawn from page 155 of the National Atlas, United States Geological Survey, 1970).

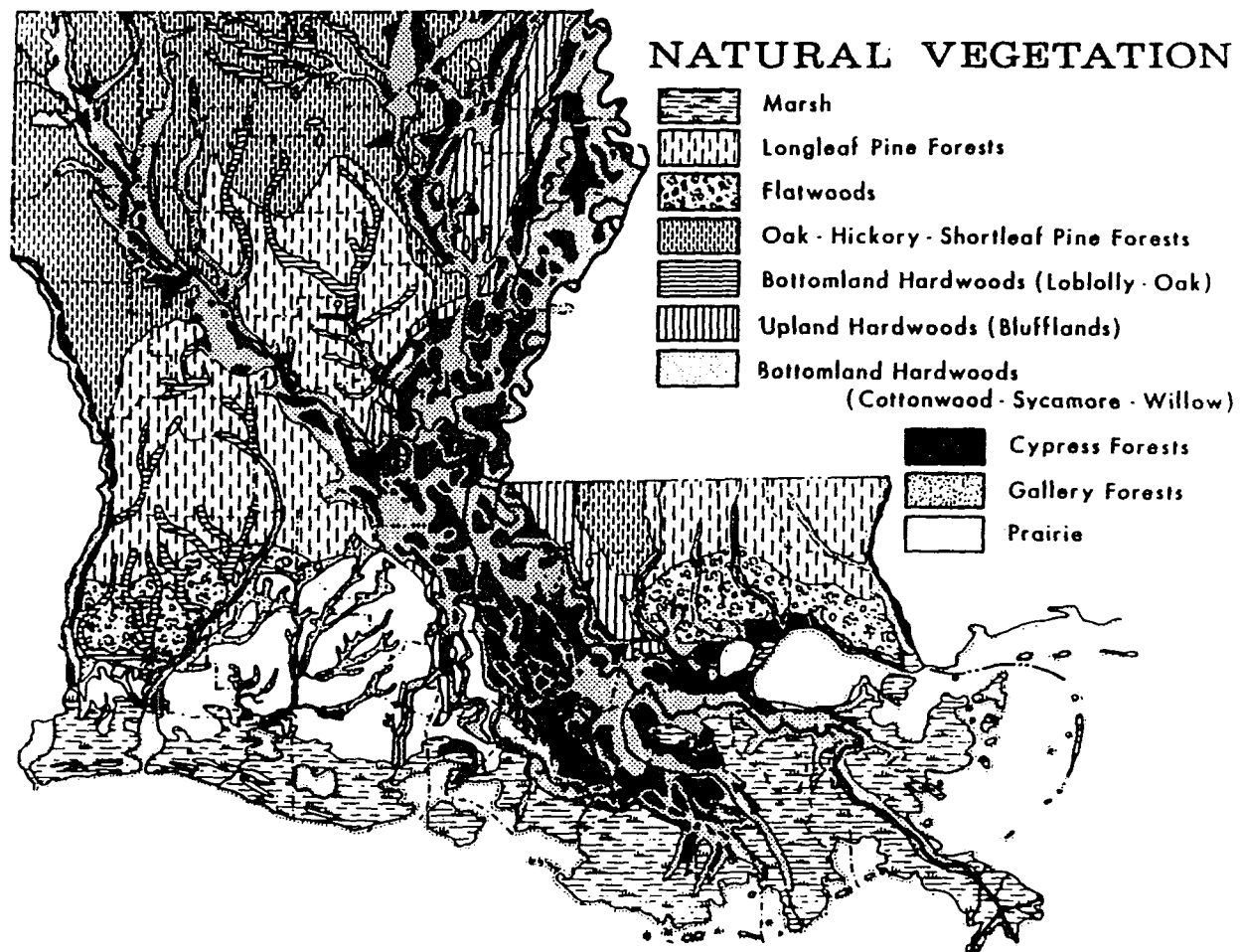


FIG. 3. Natural vegetation regions of Louisiana (from Newton, 1972).

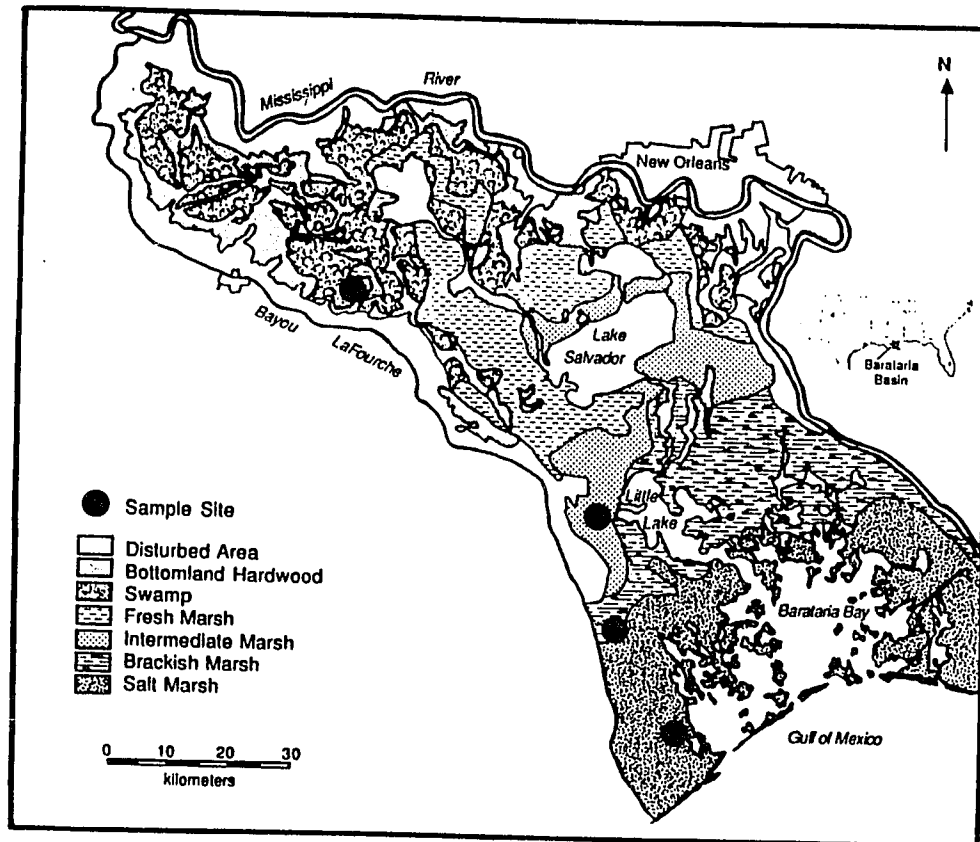


FIG. 4. Vegetation zones and sample area locations within Barataria Basin, Louisiana.



from the adjacent developed area (Bahr et al. 1983). Water eventually drains into Barataria Bay and the Gulf of Mexico. Diurnal tides average about 30 cm at the coast. Meteorologic tides, which may elevate water levels even higher, are also common events (Gosselink 1984).

Conner et al. (1986) provide an extensive list of plant species of the major physiographic regions of the Barataria Basin which are shown in Fig. 4. The basin is flanked by levees which were once covered with bottomland hardwood forest, but which are now cleared and utilized for residential areas, roads, industry and agriculture. Bottomland hardwoods are still present along the lower portions of the levees and in other elevated areas of the basin, such as spoil banks. Spoil banks and natural levees provide an environment for trees and herbaceous plants which may not otherwise be found in the wetter portions of the basin.

Cypress-tupelo swamps are present in the northern portion of the basin and extend southward adjacent to the levees. The primary species are cypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatica*) which may occur in pure stands or in mixtures of the two. Ashes (*Fraxinus*) and maples (*Acer*) may also be present. In addition to the woody understory, many species of floating aquatics and emergent plants can be found on the flooded swamp floor.

Herbaceous marshes fill the rest of the basin. The marshes are subdivided into fresh, intermediate, brackish and salt zones based primarily on vegetation associations established by Penfound and Hathaway (1938) and Chabreck (1972). These vegetation associations within the basin correspond to a salinity gradient of 0.1 to 28.1 ppt (Chabreck 1972) which causes vegetation diversity to decrease and dominance to increase from the fresh to salt marshes (Gosselink 1984).

The fresh marsh areas studied are floating marshes; locally referred to as "flotant". The vegetation communities of the flotant and attached fresh marsh are similar (Conner et al. 1986, Sasser and Gosselink 1984). They support a diverse plant community of more

than 70 species, but are dominated by maidencane (*Panicum hemitomon*) which may comprise 70% of the total aboveground biomass (Sasser and Gosselink 1984). Other important species, particularly in the flotant, are the ferns *Thelypteris palustris* and *Osmunda regalis*, and vines *Vigna luteola* and *Polygonum sagittatum* (Sasser and Gosselink 1984).

All marshes in the Barataria Basin have considerable spatial variation, but the intermediate marshes seem to be the most varied. In a study of a 90-km<sup>2</sup> site in the basin Sasser et al. (1982) identified six plant associations using statistical clustering techniques and noted even more complex visual patterns with aerial imagery. Local influences of fresh and brackish water, along with slight elevational changes are suggested as the primary causal factors of this variation. Some of the major species are *Spartina patens*, *Phragmites australis*, *Sagittaria falcata* and *Bacopa monnieri* (Gosselink 1984).

Plant diversity is further decreased in the brackish marsh where 18 species have been reported. *Spartina patens* is dominant in this zone. *Distichlis spicata*, *Juncus roemerianus*, and *Scirpus* spp. are some of the more commonly found species (Conner et al. 1986).

*Spartina alterniflora* is the dominant plant in the salt marshes of the Barataria Basin, often found in extensive monospecific stands. *Juncus roemerianus*, *Distichlis spicata* and *Spartina patens* are other common species in the salt marshes (Conner et al. 1986).

## METHODS

### *Clip plots*

The vegetation component of the study was part of a larger study conducted under the auspices of the Louisiana Offshore Oil Pipeline (LOOP) monitoring program, which has involved yearly sampling of vegetation composition and productivity in designated marsh sites. Four marsh zones: fresh (FC, FA and FB), intermediate (IC and IP),

brackish (BC) and salt (SC and SB), were sampled in this study. Sample sites are located within 1 to 89 km of the urban development along Bayou LaFourche (Fig. 4-8). The fresh marsh sites are situated on Lake Boeuf. Site FC is located within 1 km from the swamp forest. Site FA is situated approximately 1 km south of FC within 0.5 km swamp forests. The third fresh marsh site (FB) is approximately 2 km northwest of site (Fig. 5). Intermediate marsh sample site IP is located approximately 10 km from the fresh marsh zone, 5 km from the nearest brackish marshes, and situated less than 1 km from the development associated with Clovelly Farms (Fig. 6). The second intermediate site, IC is approximately 6 km southeast of IP and 4 km from brackish marshes. Only one brackish marsh site was sampled (Fig. 7). This site, BC is located approximately 10 km from the nearest intermediate marshes and only meters from the salt marsh zone. Two salt marsh sites were sampled (Fig. 8). Site SC is 17 km from the brackish marsh zone and within 1 km of Bay Macoin. Site SB is on Lake Jesse approximately 19 km from the brackish marsh.

At each site sampling was conducted along randomly selected transects which ran approximately perpendicular to the nearest water channel (sites could be reached only by boat). Sample plots were placed at every 20 meters along 200-m transect lines. If the plot location was found to be centered over open water the plot was relocated 1 m to the side. Plots are numbered sequentially with the site nearest the water access being number one. At each plot all plants, live and dead, contained within a quadrat ( $0.10 \text{ m}^2$  in the intermediate marsh and  $0.25 \text{ m}^2$  in all others) were clipped to ground level and placed in plastic bags. Recently fallen dead plant material on the surface of each plot was removed along with clipped plants. Only vascular plants were included in the collection. Live plants were sorted by species and individual stems were counted.

The same sampling procedure was conducted in 1985 and 1986. Samples from the sampling year 1985 provide 48 of the 62 samples used in this study. The pollen

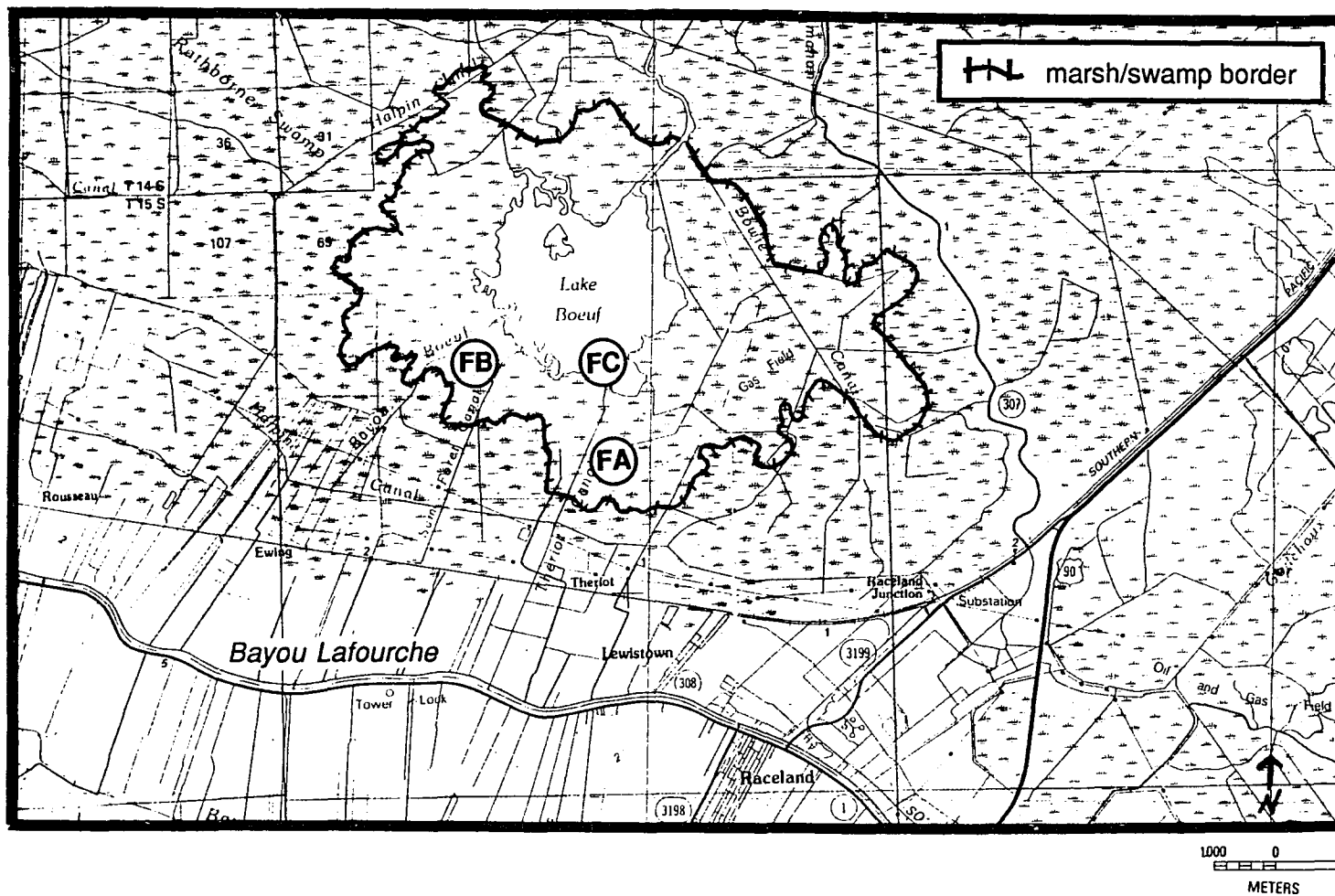


FIG. 5. Location of fresh marsh sample sites (FC, FA and FB) (adapted from U.S. Geological Survey, 1983a).

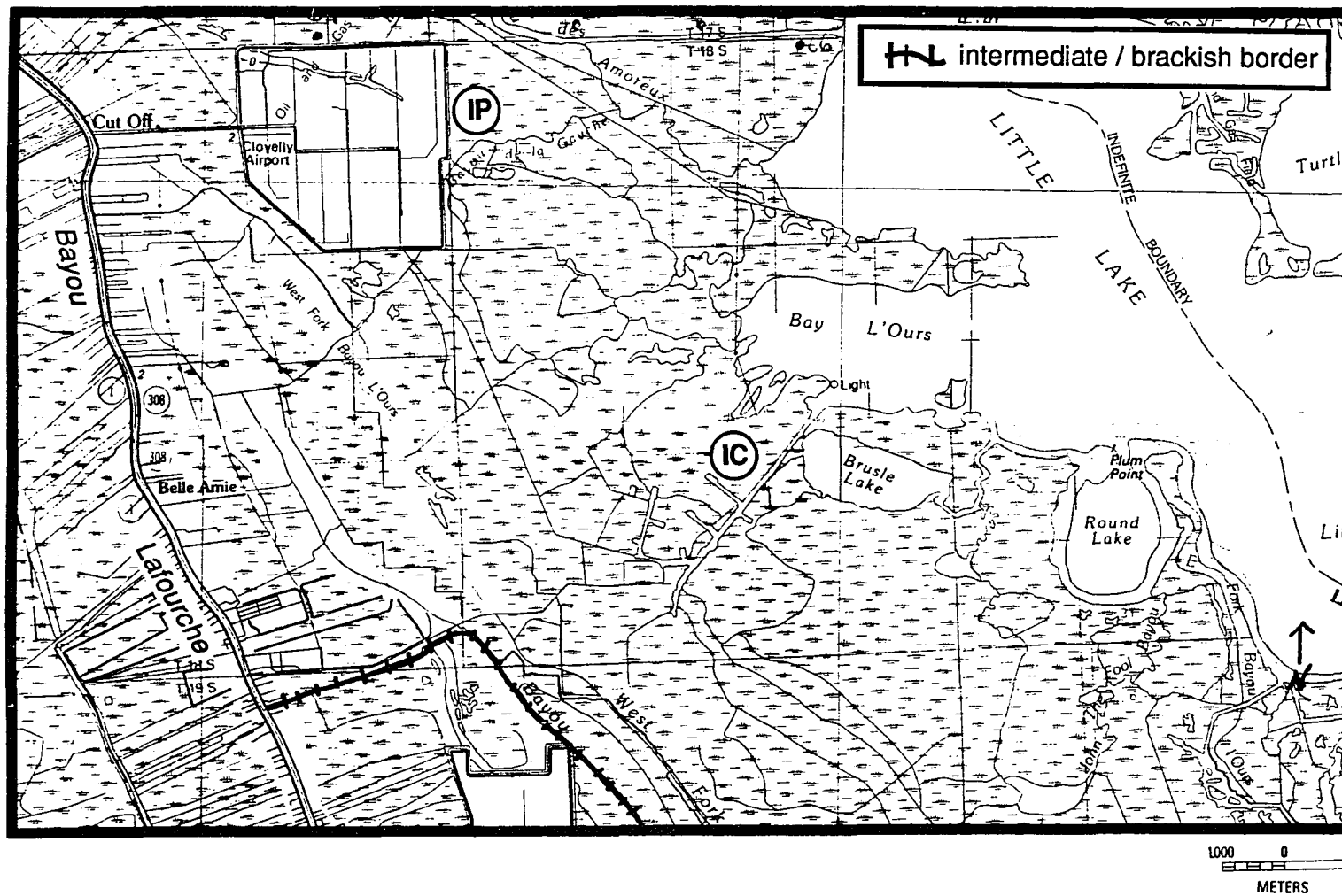


FIG. 6. Location of intermediate marsh (IC and IP) sample sites (adapted from U.S. Geological Survey, 1983a and 1983b).

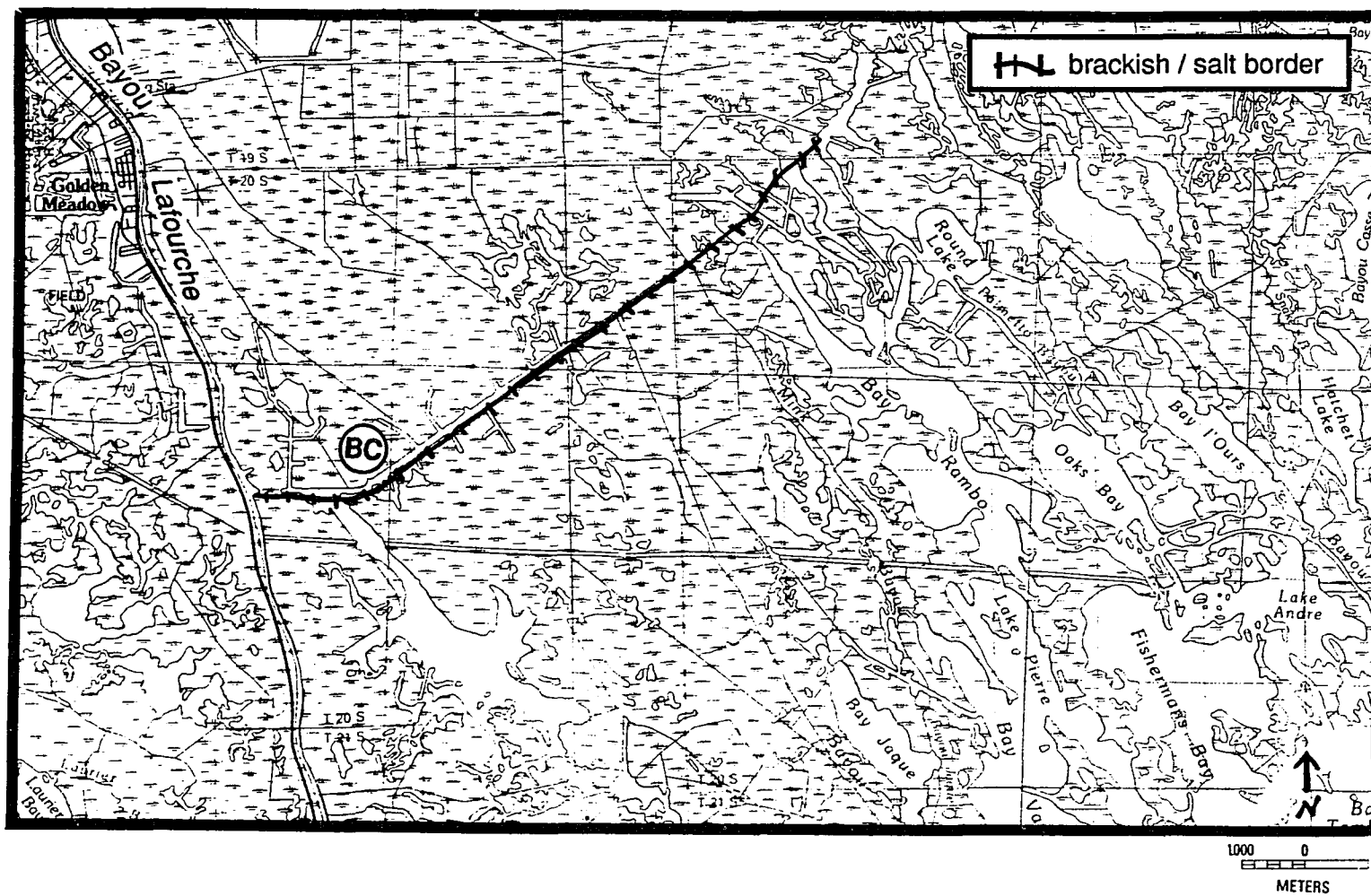


FIG. 7. Location of brackish marsh (BC) sample site (adapted from U.S. Geological Survey, 1983b).

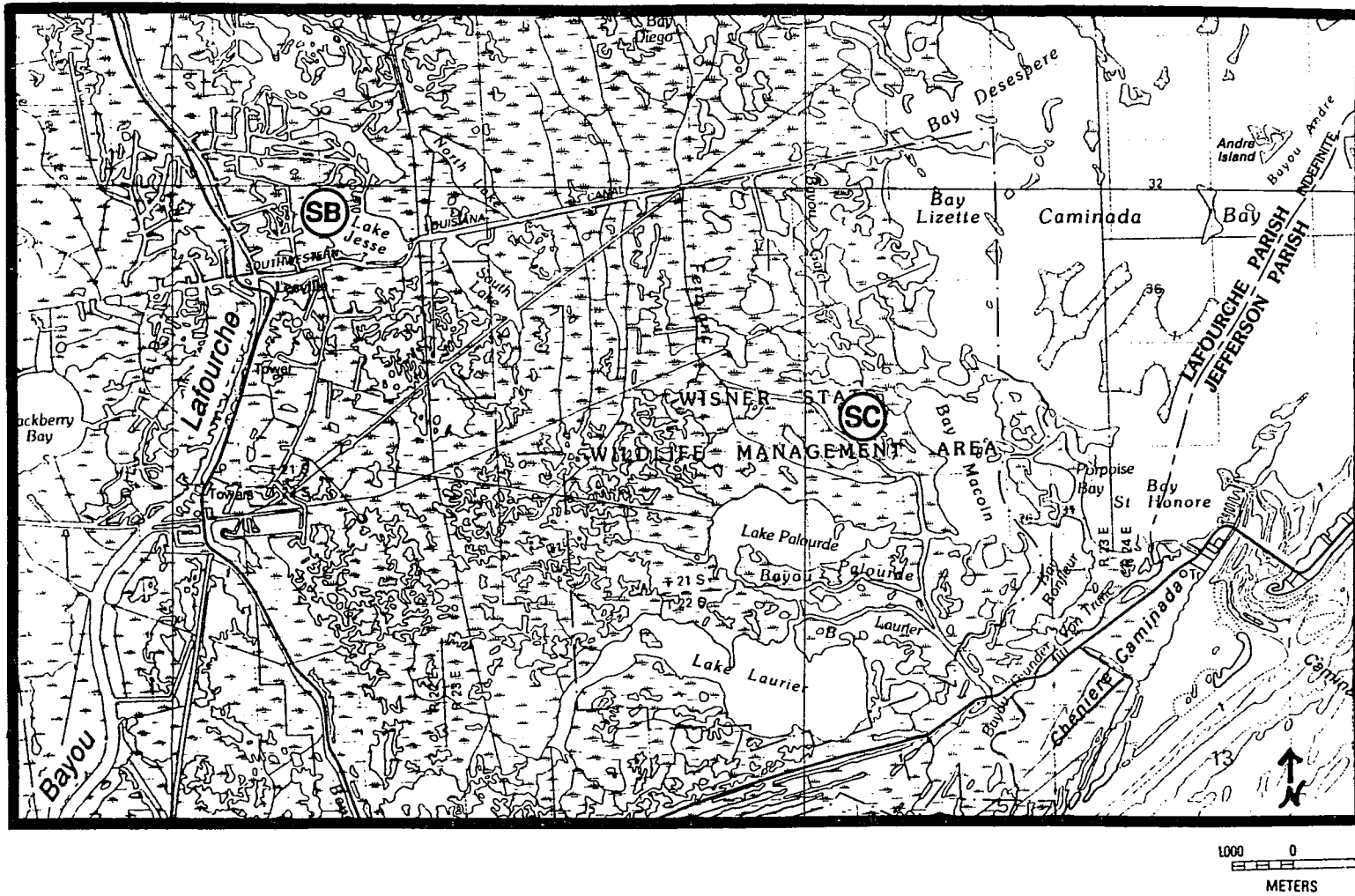


FIG. 8. Location of salt marsh (SC and SB) sample sites (adapted from U.S. Geological Survey, 1983b).

diagram and distribution characterization are based on samples from 1985. Statistical analyses utilize all samples: 25 fresh marsh, 11 intermediate, 13 brackish and 13 salt.

### *Pollen sampling and analysis*

Samples for pollen rain were taken after plant debris had been cleaned from the plot. Material was obtained by hand-grab to a depth of approximately 3 cm.

Pollen was concentrated from 0.85 to 1.80-ml subsamples, processed with conventional HF and acetolysis techniques (Faegri and Iversen 1975), stained and mounted in silicone oil. Those samples with large amounts of plant debris were sieved and washed in gooch crucibles immediately after treatment with KOH. One tablet of exotic *Lycopodium* spores (ca. 12,100 grains per tablet) was added to each sample to permit calculation of pollen concentrations. A minimum of 250 grains was counted on each slide.

Routine counting was completed at 400x magnification. Identifications were made with the aid of published keys (Kapp 1969, McAndrews 1973, and Moore and Webb 1978) and reference collections. All pollen with characteristic Cupressaceae-type split were counted as Taxodiaceae-Cupressaceae-Taxaceae (TCT) type, recognizing the potential contribution of *Taxodium distichum*, a local and common member of Taxodiaceae which may split in a similar fashion. Those grains with visible exit papillae (Kapp 1969), however, were counted as *Taxodium*. Microforaminifera were counted on slides prepared for pollen analysis. In the case of samples in which Foraminifera were not found, the entire slide was scanned for Foraminifera.

## RESULTS AND DISCUSSION

### *Pollen concentration*

Total concentrations of pollen and spores vary within and among marsh zones (Table 1). Concentrations are highest in the fresh marsh, but demonstrate no systematic trend



Table 1. Concentrations of pollen and spores in all surface marsh samples.

salinity zone	number per cc		
	minimum	maximum	mean
fresh	10749	198915	49720
intermediate	14680	42625	26378
brackish	18318	75413	38213
salt	20251	62753	39954

among salinity zones. Thus, palynomorph concentration is not a useful criterion for discriminating among marsh salinity zones. Concentrations of individual pollen types closely correspond to respective percentages within a sample. In the following discussion the terms "abundances" and "values" are used in a collective sense, referring to both percentages and concentrations. Since concentration data provide little additional information beyond that provided by percentage data only a percentage diagram is presented (Fig. 9).

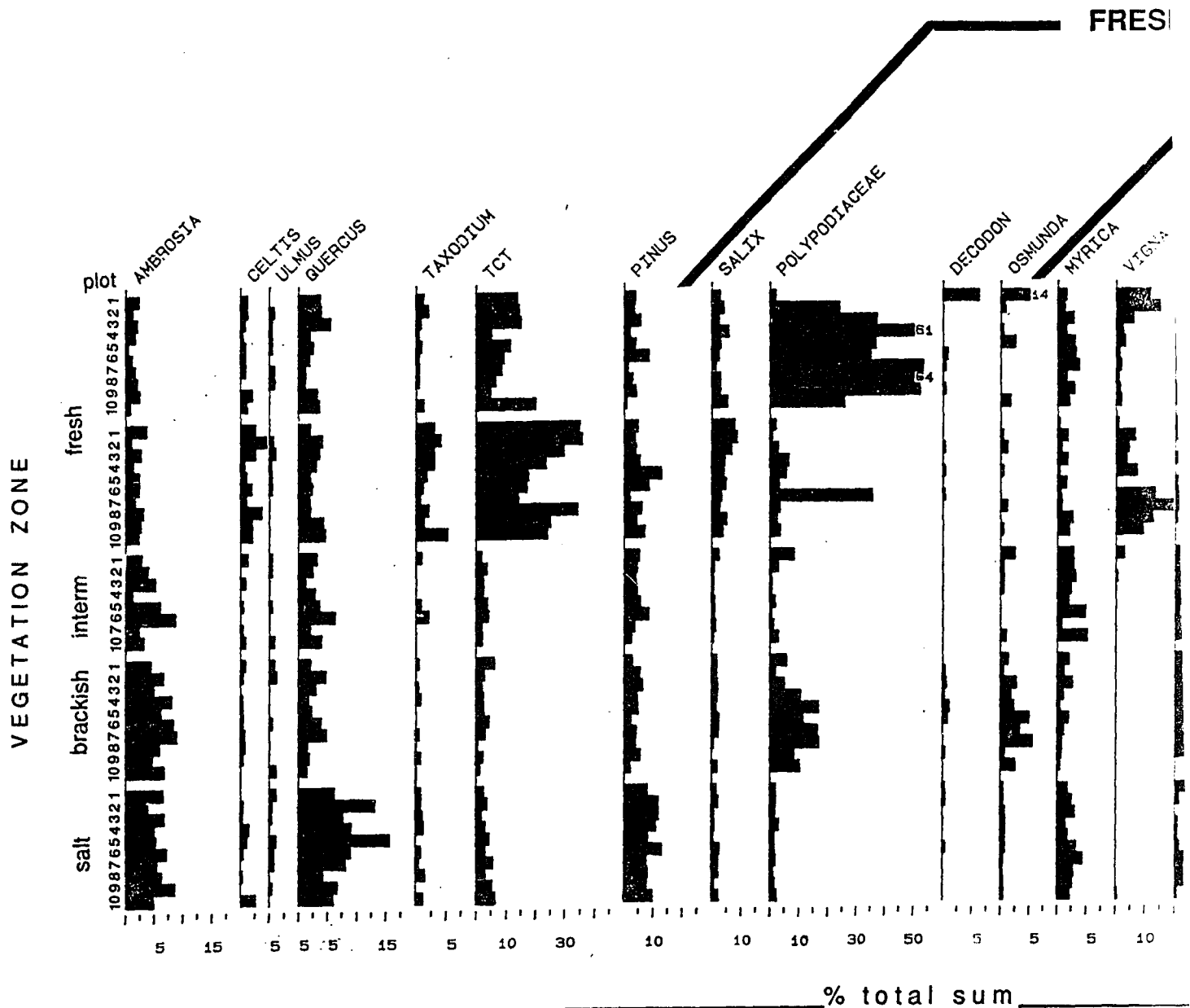
#### *Pollen sources and distribution*

In the following discussion of pollen sources terminology generally follows that of Janssen (1966, 1973). Local pollen is that pollen produced close to the sample source and may be characterized by high variability. Extra-local pollen sources are those within a few hundred meters of the sample site. Both are expected to be represented by percentages higher than regional percentages. Regional sources are those located within a vegetation formation and extra-regional are those beyond the area of the vegetation formation where the samples were collected. The estuarine nature of the study area presents conditions somewhat different from that for which these concepts were originally developed. For purposes of this discussion the following assumptions are made. Local pollen sources are those plants found within sample quadrats. Extra-local sources are those found within the marsh salinity zone as described and listed by Conner et al. (1986) and by extended surveys of the LOOP project (Peterson et al. 1986; Sasser and Gosselink 1984; Sasser et al. 1982 and 1984), but not within sample plots. Regional sources are those natural vegetation types located within non-marsh vegetation zones in Barataria Basin, and extra-regional are those outside the drainage area of the basin.

*Local sources* - Results of the clip plots harvests are presented in tables 2-6. There is little direct relationship between pollen abundances and stem counts, or presence of a

# BARATARIA BASIN MARSHES, LOUISIANA MODERN POLLEN RAIN

Analyst G.L Chmura 1987



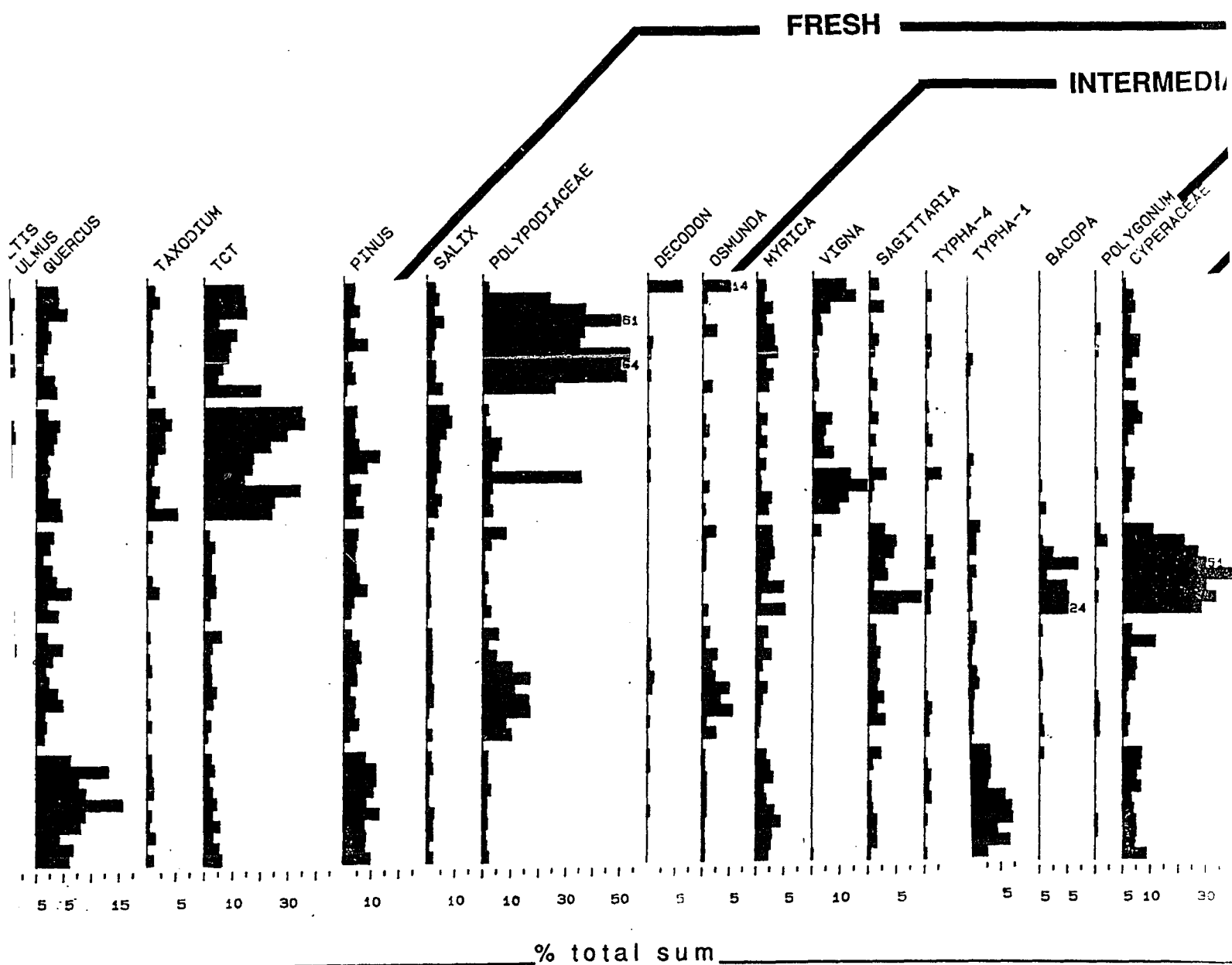
TYPHA-1= *Typha angustifolia* type, TYPHA-4= *Typha latifolia* type, COMP-TUB= Compositae-tubuliflorae type, CHENO AM=C

FIG. 9. Pollen percentages (based on total sum) of surface marsh samples from four salinity zones in Barataria B. Samples described in figure were collected in September 1985.



# BARATARIA MARSHES, LOUISIANA RAIN

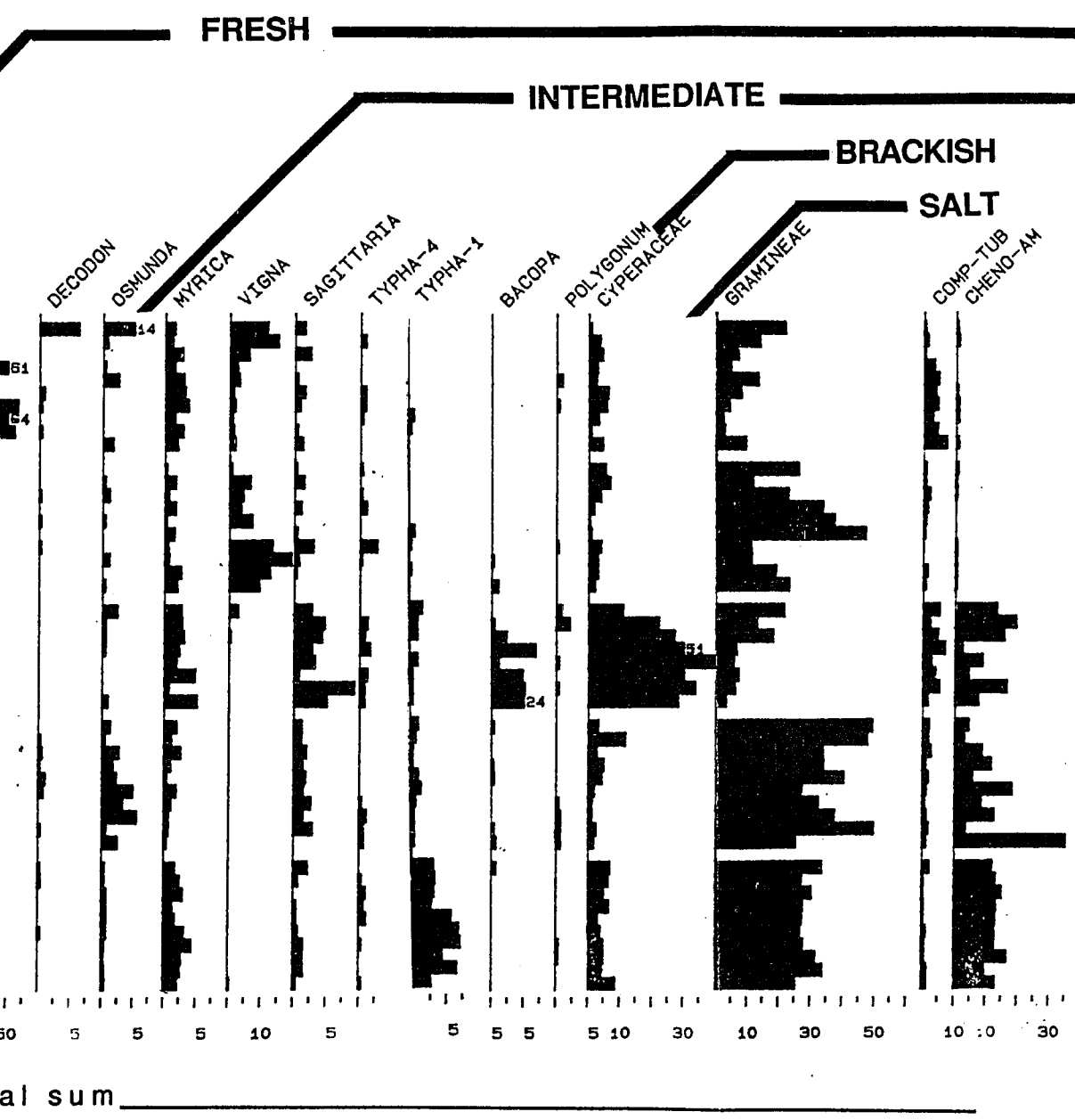
Analyst G.L Chmura 1987



*Typha angustifolia* type, TYPHA-4= *Typha latifolia* type, COMP-TUB= Compositae-tubuliflorae type, CHENO AM=Chenopodiaceae-Amaranthaceae type

Percentages (based on total sum) of surface marsh samples from four salinity zones in Barataria Basin, Louisiana, USA.  
The figure were collected in September 1985.





ae-tubuliflorae type, CHENO AM=Chenopodiaceae-Amaranthaceae type

salinity zones in Barataria Basin, Louisiana, USA.





TABLE 2. Stem counts of plants in 0.25m<sup>2</sup> plots along fresh marsh transects at site FC.

PLOT	1985 SAMPLING										1986 SAMPLING	
	FC1	FC2	FC3	FC4	FC5	FC6	FC7	FC8	FC9	FC10	FC2	FC10
SPECIES	NUMBER OF STEMS											
<i>Acnida tamaracina</i>	2											
<i>Alternanthera philoxeroides</i>	1											
<i>Cuscuta indecora</i>							0a					
<i>Cyperus</i> spp.		10		1			10	3			3	
<i>Cyperus polystachyos</i>											11	42
<i>Decodon verticillatus</i>		1		1			4	1			1	
<i>Eleocharis rostellata</i>			28	20	32	20	62	3	7		29	9
<i>Eupatorium capillifolium</i>							3					
<i>Eupatorium coelestinum</i>												5
<i>Hydrocotyle ranunculoides</i>	3	3	4		1		4		1	1		
<i>Hypericum walteri</i>							6	4				1
<i>Ipomea sagittata</i>					0a	0a	0a	0a	0a			
<i>Juncus</i> sp.							7					
<i>Juncus marginatus</i>								2				1
<i>Leersia oryzoides</i>	3	12	17	6	20	6	2		12	11	26	
<i>Panicum hemitomon</i>	58	83	69	64	113	121	52	108	238	85	111	67
<i>Panicum scoparium</i>				5			3		12			
<i>Polygonum sagittatum</i>	0b	0a	0a	0a	0a	0a	0b	0a	0a	0a		0a
<i>Rynchospora inexpansa</i>												4
<i>Sacciolepis striata</i>	23											
<i>Sagittaria latifolia</i>		6	9	3			8	3		1	7	11
<i>Saururus cernus</i>		3										
<i>Solidago</i> sp.	1	2	6	10		12	11	15	3	2		
<i>Solidago sempervirens</i>											4	7
<i>Thelypteris palustris</i>		29	23	31	4	13	13	28	21	10	17	25
<i>Vigna luteola</i>	0a	0a	0a	0a	0a	0a	0a	0a	0a	0a	0a	
<i>Xyris iridifolia</i>												5

<sup>a</sup>Species present as an vine, no stem count determined.

TABLE 3. Stem counts of plants in 0.25m<sup>2</sup> plots along fresh marsh transects at sites FA and FB.

PLOT	-----1985 SAMPLING-----										1986 SAMPLING		
	FA1	FA2	FA3	FA4	FA5	FA6	FA7	FA8	FA9	FA10	FA3	FA10	FB8
SPECIES	----- NUMBER OF STEMS -----												
<i>Aster subulatus</i>											5		
<i>Decodon verticillatus</i>													31
<i>Eleocharis spp.</i>													10
<i>Eupatorium spp.</i>													22
<i>Eupatorium capillifolium</i>							1	1					
<i>Hydrocotyle ranunculoides</i>											2		2
<i>Hypericum wateri</i>													18
<i>Leersia oryzoides</i>	14	9	10	3	5	13	3	9	16	15	13	19	6
<i>Panicum hemitomon</i>	91	49	125	72	88	90	56	91	125	134	152	109	72
<i>Polygonum sagittatum</i>							0a						0a
<i>Rynchospora inexpansa</i>													4
<i>Sagittaria falcata</i>		4		9									4
<i>Solidago sempivirens</i>								1	19				
<i>Thelypteris palustris</i>							1		1			1	4
<i>Vigna luteola</i>	0a	0a	0a	0a	0a	0a	0a		0a	0a	0a	0a	0a

aSpecies present as a vine, no stem count determined.

TABLE 4. Stem count of species in 0.1m2 plots along intermediate marsh transects.

PLOT	-----1985 SAMPLING-----								1986 SAMPLING		
	IC1	IC2	IC3	IC4	IC5	IC6	IC7	IC10	IC4	IC6	IP10
SPECIES	-----NUMBER OF STEMS-----										
<i>Aster tenuifolius</i>				6		2					
<i>Bacopa monnieri</i>						0b	0b	0b			
<i>Cyperus polystachus</i>								1			
<i>Distichlis spicata</i>	1	30	15								
<i>Eleocharis cellulosa</i>						20	13				
<i>Eleocharis macrostachya</i>	14	4	303	687	258	428	456	547			
<i>Eleocharis rostellata</i>								3	439	269	331
<i>Lythrum lineare</i>				1			2		1		
<i>Scirpus olneyi</i>			3	13	1	23	21	14	13		
<i>Setaria geniculata</i>		2	1	3	27	6			15	8	
<i>Setaria magna</i>								1			
<i>Spartina patens</i>	137	110	35	58	69	20	21	42	103	51	2
<i>Vigna luteola</i>		0a	0a		0a						

aSpecies present as a vine, no stem count determined.

bSpecies present as low ground cover, no stem count determined.

TABLE 5. Stem count of species in 0.25m<sup>2</sup> plots along brackish marsh transects.

PLOT	-----1985 SAMPLING-----										1986 SAMPLING		
	BC1	BC2	BC3	BC4	BC5	BC6	BC7	BC8	BC9	BC10	BC1	BC2	BC4
SPECIES	-----NUMBER OF STEMS-----												
<i>Distichlis spicata</i>	101								75		8		
<i>Spartina alterniflora</i>	55	92	112	88	154	96	74	12	59	35	50	30	46
<i>Spartina patens</i>	13					119		274					

TABLE 6. Stem count of species in 0.25m<sup>2</sup> plots along salt marsh transects.

PLOT	-----1985 SAMPLING-----										1986 SAMPLING		
	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9	SC10	SB1	SC8	SC10
SPECIES	-----NUMBER OF STEMS-----												
<i>D. spicata</i>											11		
<i>Spartina alterniflora</i>	38	46	68	45	40	46	38	61	59	57	77	9	71
<i>Spartina patens</i>											39		

taxon in a plot (Fig. 9, counts for all samples and taxa are listed in Appendix 1). Because much of the surface litter was cleaned from plots prior to sediment sampling, however, the pollen rain would not be likely to correspond to blooming of the sampling year. Instead, it is assumed that the samples represent an integration of pollen rain over a period which extended two to three years prior to sampling. Since most plants in the study area are perennials it is unlikely that vegetation distributions have changed significantly and clip plot data are still considered to be relevant to the pollen samples.

#### *Bacopa*

Source: Water hyssop (*B. monnieri*) was harvested in clip plots IC6 and 10. It has also been reported to occur in fresh and brackish marsh zones of Barataria Basin. *Bacopa*, however, reaches its highest densities within the intermediate marsh zone.

Distribution: Of all plots IC10 has the highest percentage and concentration of this pollen, but there is no indication of higher local values in plot IC6 where *Bacopa* was also harvested. Values for other plots in the intermediate marsh are generally higher than for other zones, indicating that extra-local values are higher in this zone.

#### Chenopodiaceae -Amaranthaceae type

Source: *Acnida tumaracina* was harvested in clip plot FC1, but no plants from either the Chenopodiaceae or Amaranthaceae family (with the exception of alligatorweed, *Alternanthera philoxeroides*) were harvested in other plots.

Distribution: Concentrations of this type are not detectably higher for plot FC1, in fact, the fresh marshes have the lowest frequency of occurrence, concentrations and percentages of all salinity zones. Higher percentages and concentrations of this type in other salinity zones is likely due to redistribution of existing sources and introduction of new sources through tidal transport.

### Compositae-Tubuliflorae type

Source: There are many sources of this type occurring throughout the study area. *Solidago spp.*, *Eupatorium capillifolium* and *E. coelestinum* were harvested within clip plots of both fresh marsh sites. *Aster tenuifolius* was harvested in plot IC7.

Distribution: There is no indication of local values. Extra-local values are highest in the fresh floatant and intermediate marshes.

### *Cuscuta*

Source: Dodder (*C. indecora*) is a parasitic plant growing on other herbaceous plants in the fresh marshes. It was harvested in plot FC7. Since it is also reported to occur within salt marshes of the basin it probably can occur in brackish and intermediate zones as well.

Distribution: No grains were found within plot FC7, thus both local and extra-local values are similar and uniformly low.

### Cyperaceae

Source: *Cyperus sp.* was harvested in plots FC2, 4, 7 and 8. *Eleocharis rostellata* was harvested in plots FC3, 4, 5, 6, 7, 8, and 9. *Carex* and *Scirpus spp.* have also been found in the fresh marsh study area. All three genera have been reported in the intermediate marsh study area and both *Eleocharis* and *Scirpus* have been found in the brackish marsh study area.

Distribution: Local deposition does not seem to be significant since fresh marsh values are within the range of salt and brackish marsh regional values. Highest values of extra-local deposition occur in the intermediate marsh.

### *Decodon*

Source: *Decodon verticillatus* was harvested in plot FC8. It has not been reported in other marsh salinity zones.

Distribution: There is no evidence that local values are higher than extra-local values within the fresh marsh. These extra-local values, however, are higher than regional values of other salinity zones.

### Gramineae

Source: Grasses were harvested in all clip plots. A single species, saltmarsh cordgrass (*Spartina alterniflora*) was collected in the salt marsh. This species along with two others, spike grass (*Distichlis spicata*) and saltmarsh hay (*Spartina patens*) were found within the brackish marsh plots. Plots in the intermediate marsh included both spike grass and saltmarsh hay as well as *Setaria geniculata* and *Setaria magna*. Four species of grasses were found in the fresh marsh plots: *Panicum hemitomom*, *Leersia oryzoides*, *Panicum scoparum*, and *Sacciolepis striata*.

Distribution: Highest abundances of grass pollen are in the brackish marshes where grasses were the only local pollen source. Although *Spartina alterniflora* was the only source of local pollen in the salt marsh, percentages are not as high. These lower values could be due to redistribution and removal of grass pollen during tidal flooding, or could be a reflection of lower pollen productivity of *Spartina alterniflora*, as suggested by Clark (1985).

### *Polygonum*

Source: *P. sagittatum* was harvested in all FC plots and plat FA7. *Polygonum punctatum* is reported to occur in fresh and intermediate marshes of the study area, but was not harvested in clip plots.



Distribution: Values show no distinction with local deposition or extra-local deposition, since the brackish marsh range is as high as the fresh marsh range.

#### Polypodiaceae

Source: *Thelypteris palustris* was harvested in all fresh marsh plots except FC1, FA7 and 9. *Woodwardia virginica* is also reported in fresh marshes of the study area.

Distribution: Values in the flotant, particularly, appear to correspond to local deposition, where both percentages and concentration are distinctively higher. The ubiquitous occurrence of this spore indicates that there is considerable deposition through water transport down basin, and probably through tidal sources as well.

#### *Sagittaria*

Source: *S. latifolia* was harvested in plots FC2, 3, 4, 7, 8 and 10. Bulltongue (*S. falcata*) was harvested in plot FA4. Both species are also reported to occur within intermediate marshes of the study area.

Distribution: Values provide no indication of local deposition or extra-local deposition in the fresh marsh. In the intermediate marsh, however, extra-local values are distinctly higher, possibly reflecting a greater source here.

#### Umbelliferae

Source: *Hydrocotyle ranunculoides* was harvested in plots FC1, 2, 3, 5, 7 and 10. *Ptilimnium capillaceum* is also reported to occur within the fresh marsh study area. *Hydrocotyle* sp. have been reported in the intermediate marshes of the study area.

Distribution: Fresh marsh values do not indicate local deposition, but are interpreted to represent extra-local values which are higher than in any other zone.

### *Vigna*

Source: Deer pea (*V. luteola*) is a member of the Leguminosae. This vine was harvested in all fresh marsh plots with the exception of FA8. It was harvested in plots IC2, 3 and 5, as well. It is not reported to occur in other regions of the basin.

Distribution: The occurrence of *Vigna* pollen is extremely local. A single grain was found in SC10, indicating that water and tidal transport are not important in distribution of this pollen. Local values for percentages and concentration are high.

*Extra-local sources* - Extra-local sources are those reported to occur in the marshes of Barataria Basin (Conner et al. 1986), but were not harvested in clip plots.

### *Cephalanthus*

Source: Buttonbush (*C. occidentalis*) occurs in the study site, but was not present in the clip plots. It may also occur in crevasse and natural levee environments.

Distribution: One grain was found in plot FA5.

### *Hymenocallis occidentalis*

Source: The spider lily is reported within the fresh marshes and swamp forests of the basin.

Distribution: A single grain was found in sample FC1.

### Malvaceae

Source: Five species are found in fresh marshes, swamp forests and disturbed areas of the basin. This type is primarily represented by seashore mallow, *Kosteletzkya virginica* and halberd-leaved marsh mallow, *Hibiscus militaris* in the fresh and intermediate marshes of the study area, but neither were part of clip plot samples.

Distribution: A single grain was found at site BC8.

### *Myrica*

Source: Wax myrtle (*M. cerifera*) occurs on levees as well as in fresh and intermediate marshes of the study area, but not in the clip plots.

Distribution: The 100% frequency of occurrence indicates that this type is well dispersed in the basin, but regional values are low. Relatively high values in the salt marsh indicate the importance of tidal water transport.

### Nymphaceae

Source: The white waterlily (*Nymphaea odorata*) grows within aquatic habitats of the fresh marshes of the study area.

Distribution: Regional values are as high or higher than extra-local values demonstrating significant water transport.

### *Osmunda*

Source: Royal fern (*O. regalis*) grows within fresh marshes of the study area, but was not recorded within clip plot samples. This species also occurs with *O. cinnamomea* in the swamp forest.

Distribution: Abundance is highest in the fresh marsh, representing extra-local values. Percentages are an order of magnitude lower in other salinity zones, although some brackish marsh samples had a relatively high concentration of grains. The 100% frequency of occurrence in brackish and salt marshes indicates that this type is subject to water and tidal transport. Janssen (1984) also found similar extra-local percentages for *O. cinnamomea* in swamp forests of Minnesota.

Pontedariaceae type

Source: Pickerelweed, *Pontedaria cordata* has been reported in the fresh marshes of the study area, but was not harvested in the clip plots.

Distribution: Highest concentrations and percentages of this type occur in the fresh marsh, indicating that extra-local values may differ from regional values.

*Rhexia*

Source: Meadow beauty, *R. alifanus* has been reported to occur in fresh marshes of the basin.

Distribution: A single grain was found in BC9.

*Salix*

Source: Willow (primarily *S. nigra*) occurs in the study site, but was not present in the clip plots. It is also a component of bottomland hardwood swamps, crevasse, levee and spoil bank environments.

Distribution: Concentration and percentages are highest in the fresh marshes, indicating significant extra-local deposition. The next highest values occur in the salt marsh, indicating importance of tidal transport with this type.

*Typha angustifolia* type

Source: Both *T. angustifolia* and *T. domingensis* have been reported in fresh marshes of Barataria Basin, but it is likely that *T. domingensis* has been misidentified as *T. angustifolia* or even *T. latifolia* (Grace, personal communication).

Distribution: Abundances and frequencies of this species are highest in the salt marsh.

*Typha latifolia* type

Source: Common cattail, *Typha latifolia* has been reported to occur in both fresh and intermediate marshes of the study area, but was not harvested in clip plots.

Distribution: Extra-local values are within the same range as regional values.

*Regional sources* - Regional vegetation sources include swamps, bottomland hardwood forests and levee. In the following discussion the references for the vegetation of swamps and bottomland hardwood forests are Conner et al. (1986) and Newton (1972) unless otherwise specified.

*Acer*

Source: There are two species of maple in Louisiana, swamp maple (*A. drummondii*) and box elder (*A. negundo*). Both are found among bottomland hardwoods, swamp forests and spoil bank vegetation within the basin. Swamp maple also grows in the flatwoods and prairie vegetation region.

Distribution: Percentages of this type is low, generally under 1%. The frequency of occurrence is higher in both fresh marshes, most likely due to the proximity of bottomland hardwoods to these zones. The occurrence of maple represents regional, but not extra-regional sources.

*Ambrosia*

Source: Three species of ragweed grow on spoil banks within the basin. Giant ragweed, *A. trifida* also occurs in the bottomland hardwoods.

Distribution: Concentrations are highest in the brackish and salt marsh zones. Percentages are also generally higher in these zones, but not as distinctively so. Abundances in these zones probably reflect extra-regional deposition through tidal sources.

*Cabomba*

Source: Fanwort (*C. caroliniana*) occurs within freshwater aquatic habitats of Barataria Basin.

Distribution: Regional values in the salt marsh are higher than extra-local values in the fresh marsh, indicating that water transport and tidal activity are important mechanisms of dispersal.

*Carya*

Source: Four species occur in bottomland hardwoods of Barataria Basin as well as in the shortleaf pine-oak-hickory and upland hardwoods vegetation regions.

Distribution: Abundance of this type is generally low. Frequency of occurrence is greatest in the salt marsh, furthest from its sources. This indicates an extra-regional tide-dominated distribution.

*Celtis*

Source: One species, *C. laevigata*, or hackberry grows in Louisiana. It occurs in bottomland hardwoods and on spoil banks within the basin; in the shortleaf pine-oak-hickory regions and in wet, disturbed areas.

Distribution: Abundance of *Celtis* grains is generally low. Frequency of occurrence and concentrations are highest in the fresh marsh, reflecting its proximity to bottomland hardwoods within the basin.

Compositae - Liguliflorae type

Source: Both the dandelion, *Taraxacum officinale*, and sow thistle, *Sonchus asper* are common weeds in Louisiana (Brown 1945) and occur as a component of spoil bank and levee vegetation.

Distribution: A single grain was found in SC10.

### *Cornus*

Source: Roughleaf dogwood (*C. drummondii*) may occur in bottomland hardwoods and on spoil banks/levees near fresh marshes in Barataria Basin. Flowering dogwood, *C. florida* and blue-fruited dogwood, *C. stricta* may be found in shortleaf pine-oak-hickory and upland hardwoods vegetation regions and are a popular cultural element, as well (Brown 1945).

Distribution: Frequency of occurrence is low, as is abundance at most sites. Janssen (1984) indicates that *Cornus* may be poorly represented even under conditions of local deposition.

### Euphorbiaceae

Source: Nine representatives of this family are reported in the Barataria Basin. Most are common to disturbed sites or levee environments..

Distribution: A single grain was found at plot IC2.

### *Fraxinus*

Source: Ash is a dominant component of swamp forests within Barataria Basin (Conner and Sasser 1985). Three species may be present, swamp ash (*F. pennsylvanica*), green ash (*F. carolinia*) and water ash (*F. profunda*).

Distribution: *Fraxinus* grains are common in marsh samples. Highest percentages and concentrations are found in the flotant marsh. These higher regional values may be due to its upper basin location which is closest to the swamp forest.

*Juglans*

Source: Black walnut, *J. nigra*, is widely distributed on better drained sites within the bottomland forest regions of Louisiana (Brown 1945).

Distribution: Values are uniformly low, with no indication of water or tidal transport-affected concentrations.

*Limmonium*

Source: Sea lavender (*L. carolinianum*) is reported to occur on disturbed sites in Barataria Basin and does grow on the barrier islands bordering Barataria Bay.

Distribution: A single grain was found at site BC6.

*Liquidambar*

Source: Sweetgum (*L. styraciflua*) is a common component of the swamp forests within the basin (Conner and Sasser 1985), but has not been reported at the study sites.

Distribution: Percentages and concentrations of sweetgum are highest in the brackish and salt marshes which are farthest from the regional source area. These high values and the ubiquitous occurrence in the salt marsh indicate that water transport and input from tidal sources may be important.

Moraceae/Urticaceae Type

Source: The most likely source of this type is the red mulberry, *M. rubra* which grows in bottomland hardwoods. The white mulberry, *M. alba*, also exists as a cultivated tree in Louisiana (Brown 1945) and occurs in disturbed areas of the basin.

Distribution: Frequency of occurrence is low, single grains were found in fresh, intermediate and salt marsh sites.



*Myriophyllum*

Source: Eurasian watermilfoil (*M. spicatum*) is reported in aquatic habitats within the fresh marshes of Barataria Basin.

Distribution: Although no grains were found within fresh and intermediate marsh zones there were scattered occurrences in the brackish and salt marsh samples. Water transport is obviously an important mechanism for distribution of this type.

*Nyssa*

Source: Tupelogums, also referred to as water tupelo (*N. aquatica* and *N. sylvatica* var. *biflora*) are a major component of the cypress-tupelo gum and bottomland hardwood swamps within the basin. *Nyssa* also occurs in the shortleaf pine-oak-hickory, flatwoods, upland hardwoods and prairie vegetation zones.

Distribution: Values for this type are low in all zones. Low values in the fresh marsh indicate that dispersal and/or production of this type may be limited.

*Plantago*

Source: Plantain, *P. major* occurs on disturbed sites within the basin.

Distribution: A single grain was found at site FA9.

*Plantanus*

Source: American sycamore (*P. occidentalis*) occurs in the bottomland hardwoods.

Distribution: Highest frequency of occurrence is in the fresh flotant marsh, which may be closest to cultural plantings. Abundances are all uniformly low.

*Populus*

Source: Both *P. heterophylla* and *P. deltoides* are minor components of bottomland hardwood forests. *Populus deltoides* also may occur on spoil banks within the basin.

Distribution: Highest frequency of occurrence and percentage is in the brackish marsh. In general, concentrations and percentages are very low, and assumed to be regional values.

#### *Potamogeton*

Source: Slender pondweed (*P. pusillus*) occurs within aquatic habitats of fresh marshes in Barataria Basin.

Distribution: Regional values are similar to Nymphaeae in that they are as high or higher than extra-local values, demonstrating significant water transport.

#### *Quercus*

Source: This genus is nearly ubiquitous and is found in all Louisiana vegetation formations. It is also found at higher elevations on barrier beaches and may be a component of late successional spoil bank/levee vegetation.

Distribution: The distribution, ranges of concentrations and percentages of *Quercus* pollen are similar to that of *Pinus*, with highest values occurring in the salt marsh. Thus, extra-regional values are probably elevated due to tidal transport of grains.

#### *Taxodium*

Source: The only source in Louisiana is the bald cypress, *Taxodium distichum*, which occurs in bottomland hardwood and cypress-tupelo swamps in Barataria Basin, as well as in wet sites of shortleaf pine-oak-hickory, flatwoods and prairie vegetation regions.

Distribution: The highest frequency of occurrence and abundances of *Taxodium* grains are in the fresh marsh, close to the swamp source. Values decrease with increasing salinity to the brackish marsh. Increases in relative percentages and concentration in the salt marsh may be due to introduction of tidal water.

### Taxodiaceae-Cupressaceae-Taxaceae (TCT) type

Source: The primary source of this type in Louisiana is the bald cypress, *Taxodium distichum*, noted above. Southern white cedar (also called Atlantic white cedar), *Chamaecyparis thyroides*, and southern red cedar, *Juniperus silicicola* are members of the Cupressaceae reported to naturally occur within Louisiana. Eastern red cedar, *Juniperus virginiana* is widely planted as an ornamental (Brown 1945).

Distribution: Concentrations and percentages of TCT type grains are distinctly higher in fresh marshes. This abundance is probably due to the proximity of the cypress in the upper reaches of the basin.

### *Ulmus*

Source: American elm (*U. americana*), slippery elm (*U. rubra*), and cedar elm (*U. crassifolia*) occur in bottomland hardwoods within the basin. American elm also occurs on spoil bank areas.

Distribution: Frequency of occurrence is relatively uniform, with a slightly higher value in the salt marsh. Concentrations and percentages, representing extra-regional deposition, are low.

### *Vitis*

Source: Pigeon grape (*V. cinerea*) and muscadine grape (*V. rotundifolia*) occur within the bottomland hardwoods area.

Distribution: Values are uniformly low.

*Extra-regional sources* - A complete flora of Louisiana has yet to be produced (MacRoberts, 1984). To determine aspects of dispersal within the Barataria Basin estuary attempts have been made to indicate the closest potential source of each grain type. Where

possible the species and vegetation or physiographic region have been identified for each grain type, usually through reference to Brown (1945 and 1972) or Newton (1972). The annotated checklist produced by MacRoberts (1984) has been used as a cross reference and supplement to these reports.

#### *Alnus*

Source: Hazel alder (also called black alder), *A. rugosa* is common in boggy branch bottoms in the pine hills and long leaf pine flatwoods, but is absent from the Mississippi floodplain (Brown 1945).

Distribution: Occurs in low abundance in all salinity zones, but most frequently in the saltmarsh.

#### *Artemisia*

Source: Three species have been reported in Louisiana - *A. annua*, *A. ludoviciana*, and *A. vulgaris* (MacRoberts 1984).

Distribution: Occurs in low abundance in all salinity zones. Greatest abundance and frequency is in the fresh floatant marsh.

#### *Betula*

Source: River birch (also called red birch), *B. nigra* occurs along sandy branches of small streams, but is absent from the floodplain of the Mississippi (Brown 1945).

Distribution: A single grain was found in the fresh marsh (FA).

#### *Corylus*

Source: Hazelnut, *C. americana* is rare, but has been reported in Louisiana (MacRoberts 1984, Thieret 1966).

Distribution: Occurs in all salinity zones, abundances are uniformly low.

### Ericaceae

Source: There are no representatives of this family reported to naturally occur within the Barataria Basin, but several occur in other regions of Louisiana (MacRoberts 1984).

Distribution: A single tetrad was found at site SC1.

### *Fagus*

Source: Newton (1972) reports that beech (*F. grandifolia*) may occur on old natural levees and second bottoms of bottomland hardwoods, but it has not been mentioned in association with Barataria Basin vegetation zones, specifically. Beech may also be a component of the upland hardwoods vegetation region.

Distribution: All values are uniformly low. No *Fagus* pollen was found in salt marsh samples, thus indicating that tidal transport may not be important in extra-regional deposition.

### *Ostrya*

Source: The eastern hophornbeam (also called ironwood), *O. virginiana* is widely distributed along small streams of Louisiana, but not in the floodplain of the Mississippi River (Brown 1945).

Distribution: A single grain was found in FA3.

### *Picea*

Source: There is no natural occurrence of spruce in Louisiana, in the southern forests of the Mississippi alluvial valley or Gulf coastal plain. *Picea* does occur infrequently at high elevations in the central Appalachian Mountains (Delcourt and Delcourt 1984).

Distribution: A single grain was found in the brackish marsh.

### *Pinus*

Source: There are at least five species of pine naturally occurring in the shortleaf pine-oak-hickory , longleaf pine flatwoods and prairie regions of Louisiana. No pine is reported to occur naturally within the Barataria Basin, but may be present as a cultural introduction.

Distribution: Highest percentages and highest numbers of *Pinus* pollen are found in the salt marsh, indicated significant tidal transport of this type.

### *Prunus*

Source: Black cherry (*P. serotina*) occurs in the upland hardwoods vegetation zone.

Distribution: Abundances are uniform and low.

### *Tilia*

Source: Basswood, or linden (*T. americana*), occurs along streams in the shortleaf pine-oak-hickory region.

Distribution: A single grain was found at site FC2.

### *Microforaminifera*

No Foraminifera test linings were found in fresh marsh samples (Table 7). Foraminifera were found in all remaining samples with the exception of plot BC5. At least three morphological types of Foraminifera were observed: planispiral, trochospiral and uniserial. The highest concentration of forams occur in the salt marsh samples, which also happen to have the broadest range of concentrations.

Based on these modern samples it can be assumed that the presence of microforaminifera in marsh deposits suggests intermediate and higher paleo-salinities, but is not a required condition for their identification . A strong criterion for the

Table 7. Foraminifera concentration (per cc)  
in 1985 surface marsh samples.

salinity zone				
site	fresh	intermediate	brackish	salt
1	0	944	194	487
2	0	616	1928	2209
3	0	1579	919	1169
4	0	537	307	8768
5	0	3066	0	3247
6	0	1543	958	1531
7	0	4826	2640	693
8	0		3660	452
9	0		3034	841
10	0	438	3973	537
min	0	438	0	452
max	0	4826	3973	8768
avg	0	1694	1761	1993

determination of fresh marsh, however, is the absence of Foraminifera. In previous studies, the presence of Foraminifera tests have been used as an indicator of saline conditions. Since an abundance of test linings were found in intermediate marsh samples, where soil salinities can be as low as 2.7 ppt (Chabreck 1972), it must be recognized that deposits previously designated as "saline" could actually have originated under a broader salinity range.

#### *Pollen dispersal mechanisms*

Important mechanisms of pollen deposition and dispersal in conventional studies (i.e., lakes and bogs) are wind currents and resuspension in the water column. Both have been discussed in detail by other researchers (see, for example, Davis 1973; Davis and Ford 1982, Davis et al. 1971, Janssen 1973; and Tauber 1967a,b). In coastal wetlands such as those in Barataria Basin water transport may be just as important a mechanism of dispersal as wind and resuspension.

Since the entire basin eventually drains into Barataria Bay, there is considerable potential for pollen from the upper basin to be redeposited in locations downbasin, or washed into tidal waters of Barataria Bay and eventually, the Gulf of Mexico. This mechanism is most important in the case of local and extra-local pollen types which are not wind dispersed. Evidence for the significance of this transport can be seen in elevated concentrations of the fresh marsh types Nymphaeaceae pollen and the fern spores of Polypodiaceae and *Osmunda* in the brackish marsh. Transport from fresh to salt marsh is indicated by *Myriophyllum* concentrations found in the salt marsh and from fresh to all other salinity zones by *Potamogeton* concentrations in these zones.

The second mechanism, and perhaps more important in terms of regional deposition, is the effect of astronomical and meteorological tides. There are two processes by which tidal water may affect pollen assemblages within a tidal marsh, tidal smoothing of local influx (Clark and Patterson 1985) and the introduction of an additional source of regional and extra-regional pollen. The tidal smoothing effect is caused when pollen grains may



be resuspended and mixed in tidal waters. As tides retreat grains will be redeposited. Redeposition could occur in three patterns:

- 1) Grains are deposited in roughly equal number over the marsh surface, thus resulting in spatially homogeneous pollen assemblages throughout the marsh. This integration of pollen types would mask any pattern of local deposition.
- 2) Pollen grains will settle at different rates from the tidal water. Thus, as waters retreat there will be a differential sorting of pollen types across the surface of the marsh.
- 3) Whether or not sorting occurs, pollen deposition may be concentrated in areas where drainage is impeded (e.g., behind levees).

Tidal transport is most easily detected in the distribution of extra-regional pollen types. Most sources of extra-regional pollen are closest to the upper basin and these areas would be expected to have higher concentrations of extra-regional pollen due to aerial deposition. Pollen abundances of extra-regional types, however, increase in the lower basin marshes. Since concentrations of these types are generally low in the upper basin it is unlikely that a detectable proportion would be water-transported from upper basin to lower basin wetlands. Thus, it must be concluded that increases in extra-regional concentrations are due to sources in tidal water.

Indication of increased concentrations due to input from tidal sources may be found in *Ambrosia*, *Celtis*, *Nyssa*, *Quercus*, TCT type, *Taxodium*, *Ulmus* and *Pinus*. Increased frequency of occurrences of *Carya*, *Taxodium*, and *Ulmus* also may be due to introduction by tides and the tidal smoothing effect.

#### *Separation of salinity zones*

Although surface pollen does not correspond closely with vegetation as represented in clip plots, both percentage and concentration values do correspond to extra-local sources, that is, the vegetation composition of entire salinity zones (Fig. 5). When they compared the results of 10 x 10 m relevé sampling to pollen distribution, Clark and Patterson (1985)

also found that pollen distribution corresponded to broader vegetation zones (i.e., extra-local sources) within the marsh.

Liu and Lam (1985) introduced the use of discriminant analysis as an aid in paleovegetational reconstruction based on modern and fossil pollen data. This statistical method has an advantage over other similar methods, such as principal component analysis and canonical variate analysis, in that a "probability of modern analogue" can be determined (Liu and Lam 1985). This probability can be used to determine how representative a modern pollen assemblage is of the vegetation region it is assigned to. More importantly, the probability of modern analogue can be used to determine if the classification model contains a modern analogue for a fossil pollen assemblage.

In applying discriminant analysis five statistical assumptions should be made (Davis 1973). 1) The samples in each *a priori* group are randomly chosen. 2) The probabilities of an unknown sample belonging to any group are equal, unless some *a priori* probability is specified. 3) The samples used to derive the discriminant functions are correctly classified with respect to the *a priori* groups. 4) The variance-covariance matrices of the groups are statistically equal. 5) The variables are normally distributed within each group. The conditions of field sample selection assures that the first three assumptions have been met. Assumption four and five could not be met since the variance-covariance matrices of each group are singular (small sample size). Discriminant analysis, however, is a robust technique (Davis 1973, Lachenbruch 1975) and can tolerate some deviation from these assumption without affecting classification results.

Discriminant analysis was used to help identify which taxa best characterized each marsh salinity zone and to develop discriminant functions which could be later used to classify fossil pollen assemblages. The subprogram DISCRIMINANT in SPSSX (Statistical Package for the Social Sciences 1988) was used to perform a discriminant analysis using pollen percentages. Since an ultimate goal of building the classification model is to reconstruct paleommarsh environments, efforts were made to account for

sources of river-borne grains. This source is not present in modern Barataria Basin marshes, but would be a likely component of pollen assemblages of paleommarshes in much of the delta plain. Thus, the pollen sum used to compute percentages did not include those taxa which are important constituents of waters of the modern Mississippi River at flood stage (Table 2, chapter 2; Chmura and Liu, in press). These taxa, *Pinus*, *Quercus*, *Taxodium*, TCT, *Ambrosia* and Chenopodiaceae-Amaranthaceae type were also excluded from the discriminant analysis. Taxa selected for the discriminant analysis were limited to 10 groups corresponding to common vegetation occurring within the coastal marshes (i.e., extra-local sources): Gramineae, Compositae-Tubuliflorae type, Cyperaceae, *Myrica*, *Vigna*, *Osmunda*, Polypodiaceae, *Sagittaria*, *Typha angustifolia* type and *Typha latifolia* type. The combined percentages of these groups do not add up to 100% in any sample.

The predicted salinity zone of each of the 62 samples is objectively determined by the discriminant functions. A comparison of the objectively predicted group memberships with the *a priori* group memberships shows that 58 (93.55%) of the samples are correctly classified (Table 8). Calculation of probability of modern analogue (Liu and Lam, 1985) for all samples demonstrates that, within a vegetation zone, differences in sample year and location did not result in systematic difference in the pollen assemblages (Table 9).

Three discriminant functions account for all data variance: 59.10%, 33.04%, and 7.85%, respectively. Standardized discriminant function coefficients for the 10 pollen and spore types are listed in table 10. The first function discriminates fresh and brackish marshes from intermediate and salt, and partially separates fresh from brackish marshes (Fig. 10). Function two separates intermediate from the more saline marsh groups and also partially separates fresh from brackish marshes.

The stability of the classification procedure was checked by a cross validation run using data from the 14 samples from year 1986 with sample from 1985 used to derive the

Table 8. Classification results of discriminant analysis.

actual salinity zone	no. of samples	% classified			
		fresh	intermediate	brackish	salt
fresh	25	88.0	0.0	12.0	0.0
intermediate	11	0.0	90.9	9.1	0.0
brackish	13	7.7	0.0	100.0	0.0
salt	13	0.0	0.0	0.0	100.0

Table 9. Probability of modern analogue computed for pollen assemblages from surface marsh samples from four vegetation zones in Barataria Basin.

sample site	plot no.	sample year	probability %	sample site	plot no.	sample year	probability %
FRESH				BRACKISH			
FC	1	85	49.35	BC	1	85	97.78
FC	2	85	72.11	BC	2	85	67.69
FC	3	85	92.94	BC	3	85	66.73
FC	4	85	67.65	BC	4	85	93.99
FC	5	85	93.54	BC	5	85	99.77
FC	6	85	57.59	BC	6	85	85.79
FC	7	85	77.33	BC	7	85	99.92
FC	8	85	78.86	BC	8	85	96.57
FC	9	85	65.88	BC	9	85	95.47
FC	10	85	42.27	BC	10	85	81.82
FC	2	86	2.38	BC	1	86	99.90
FC	10	86	98.73	BC	2	86	61.41
FA	1	85	43.53	BC	4	86	91.23
FA	2	85	37.77	SALT			
FA	3	85	97.97	SC	1	85	2.29
FA	4	85	61.10	SC	2	85	52.24
FA	5	85	17.01	SC	3	85	47.68
FA	6	85	72.65	SC	4	85	7.86
FA	7	85	84.94	SC	5	85	23.72
FA	8	85	18.88	SC	6	85	8.65
FA	9	85	63.83	SC	7	85	5.24
FA	10	85	96.79	SC	8	85	76.17
FA	3	86	75.91	SC	9	85	63.80
FA	10	86	69.16	SC	10	85	45.95
FB	8	86	95.91	SB	1	86	44.75
INTERMEDIATE				SC	8	86	31.77
IC	1	85	0.25	SC	10	86	96.94
IC	2	85	71.95				
IC	3	85	86.47				
IC	4	85	28.72				
IC	5	85	91.76				
IC	6	85	82.80				
IC	7	85	16.91				
IC	10	85	49.74				
IC	4	86	52.40				
IC	6	86	6.17				
IP	10	86	18.12				

Table 10. Discriminant function coefficients.

Pollen and spore type	Function 1	Function 2	Function 3
Compositae-Tubuliflorae	7.746	17.545	-0.832
Cyperaceae	11.918	8.235	6.388
<i>Myrica</i>	25.059	10.426	8.798
Polypodiaceae	-0.425	1.448	5.308
Gramineae	1.928	0.461	10.495
<i>Vigna</i>	-2.413	4.127	-1.413
<i>Sagittaria</i>	24.909	15.372	22.181
<i>Osmunda</i>	4.799	4.568	19.673
<i>Typha latifolia</i>	38.377	-4.079	-3.953
<i>Typha angustifolia</i>	45.242	-43.947	-17.390
constant	-4.952	-1.741	-5.922
Percent of total variance	59.1	33.04	7.85

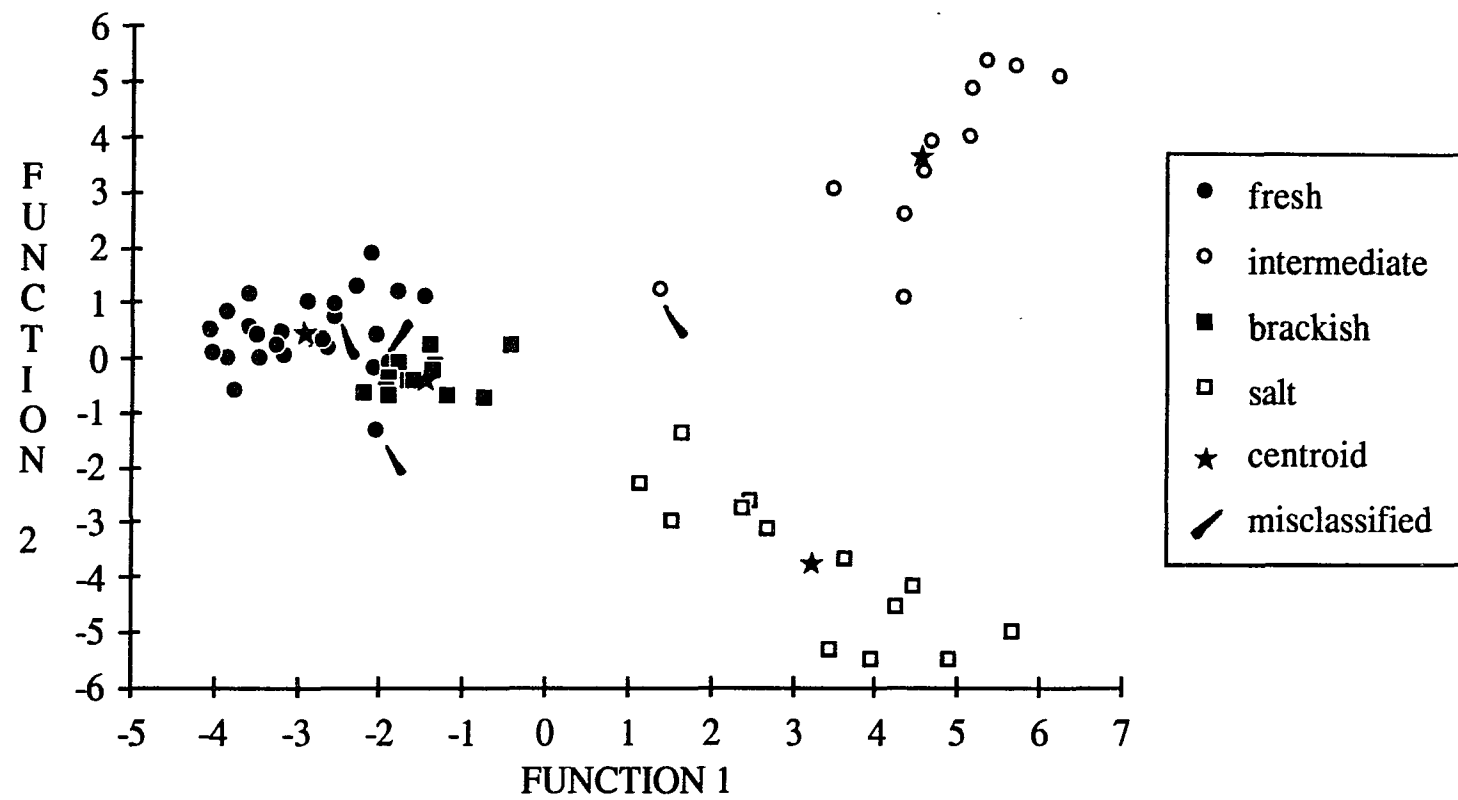


FIG. 10. Ordination of modern pollen samples from Barataria Basin marshes along discriminant functions 1 and 2.

classification functions. Classification rate for the 48 samples for 1985 is 93.75%. The correct classification rate for the 1986 test cases is 100%. This indicates a high degree of consistency in the samples, thus all were combined for establishing predictive functions.

Fresh marshes-Important discriminators separating fresh marsh from others are *Vigna* pollen and Polypodiaceae type spores (Table 10). Plants representing these groups are common in the fresh marsh. In addition to *Osmunda* and Polypodiaceae types, several forms of unidentified trilete spores occur in fresh marsh samples (Appendix 1). Coleman (1966) also noted increased numbers of sporomorphs in fresh marsh samples. *Salix* and *Decodon* plants are also common in the fresh marshes, but were not included in the discriminant analysis. Pollen percentages of both types appear to be indicators of fresh marsh. Lower regional values of *Ambrosia* and Chenopodiaceae-Amaranthaceae type may also be indicative of this zone.

Samples FC1, FA6 and FA4 are misclassified as brackish marsh. Samples FA6 and FA4 have low percentages of *Vigna* and Polypodiaceae type spores. All three samples have relatively high percentages of Gramineae. These characteristics make them statistically similar to brackish spectra.

Intermediate marsh-Discriminating taxa identified for the intermediate marsh by function one are *Sagittaria* and Cyperaceae. These are both important constituents of the vegetation communities within the intermediate marshes. Within function two *Myrica* and Compositae-Tubuliflorae type enhance the separation of intermediate from zones of higher salinity. *Bacopa* and *Polygonum*, not included in the analyses, are also common plants in the intermediate marsh community. Because they have low pollen production and limited dispersal the occurrence of both types tends to be low, but restricted to extra-local representation. Thus, the presence of these pollen types further distinguishes the intermediate marsh assemblage.



Sample IC1 is misclassified as brackish marsh. The assemblage IC1 has relatively low percentages of *Sagittaria* and Cyperaceae, the two most important criteria for distinguishing the intermediate zone. It also has the highest percentage of Gramineae within the group of intermediate marsh samples, a taxon which is a major indicator of brackish pollen assemblages.

Brackish - This zone is separated from the salt marsh zone by function 1. Important taxa for this discrimination are the fern spores of *Osmunda* and Polypodiaceae. Taxa which separate the brackish from other zones are Gramineae and Chenopodiaceae-Amaranthaceae type. Assemblages from both the fresh and intermediate marshes are misclassified as brackish. Both have relatively high values (within their zone) for Gramineae. This, accompanied by low Cyperaceae and high Polypodiaceae in the intermediate sample and lack of *Vigna* in the fresh sample characterize the assemblages as brackish.

Salt - Important taxa in distinguishing salt marshes identified in function 1 are *Typha angustifolia* type and *Typha latifolia* type. In function 2 the higher percentage of Gramineae is important in separating the salt from intermediate marsh. Regional values of *Quercus*, *Pinus*, TCT and *Ambrosia* type also help to distinguish this zone. Coleman (1966) also found increased numbers of regional and extra-regional pollen in salt marsh samples.

## CONCLUSIONS

A comparison of pollen assemblages of the four salinity zones indicates that sedimentary and water transport processes can distort pollen spectra causing over-representation of extra-regional pollen as well as fresh water pollen and spores within an estuarine system. Without knowledge of causes of such over-representation, pollen

spectra from tidal wetlands could easily be misinterpreted, assuming that regional pollen sources were primarily due to wind-deposition from nearby forests, or that presence of fresh water pollen and spore types were due to local deposition.

This distortion increases with proximity to tidal sources and can be detected only because sample areas are situated along an estuarine gradient. Such effects have not been detected in an earlier study of pollen rain in coastal marshes by Clark and Patterson (1985). This may be because that study lacked comparative sites which were subject to a variation in tidal or hydraulic activity. Proximity of the regional and extra-regional vegetation zones are also an important factor. In the Barataria Basin the salt marsh sample site is located approximately 120 km from the nearest upland forest. The marsh studied by Clark and Patterson (1985) was comparatively small (less than 1 km<sup>2</sup>) and bordered by upland forest, the vegetation zone which is the initial source of regional pollen types in that study area. The proximity of these sources may cause wind-transport to be a much more important factor in deposition, masking any variation due to deposition from tidal water.

Pollen assemblages do not correspond closely to local sources, possibly because of water flow within the system. Pollen assemblages do clearly reflect extra-local sources, that is vegetation composition of an entire marsh salinity zone. This consistent extra-local representation may also be due to the prevalence of water transport. Some regional and extra-regional pollen types, such as *Pinus* and *Quercus*, which are over-represented in the sites closer to open tidal water may be used to identify such situations in paleoenvironmental reconstructions. Thus, these estuarine processes may be an important factor in creating a characteristic pollen assemblage, or signature, for each marsh type. These results suggest that palynological analysis can be a practical tool for determination of paleomarch vegetation communities, thus paleosalinities in coastal Louisiana. Since extra-local and regional types can be identified and have characteristic values, marsh vegetation zones can be distinguished on the basis of pollen assemblages. In these

modern samples signals are clear enough to be identified through both inspection of pollen diagrams and statistical methods.

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## CHAPTER 4.

### **CLASSIFICATION OF PALEOMARSH VEGETATION ZONES: A COMPARISON OF $\delta^{13}\text{C}$ AND PALYNOLOGICAL TECHNIQUES**

#### INTRODUCTION

Two new approaches have been suggested for reconstruction of paleommarsh environments of the Mississippi delta plain. It has been demonstrated that  $\delta^{13}\text{C}$  analyses (Chapter 1, Chmura et al., 1987) and palynological analyses (Chapter 3) can distinguish among marsh vegetation zones in surface samples from marshes of the Barataria Basin, Louisiana.

The  $\delta^{13}\text{C}$  value of sedimentary carbon represents the relative proportions of C-3 and C-4 plants in the vegetation community and can be used to distinguish among fresh, intermediate and brackish/salt marsh vegetation zones (Chapter 1, Chmura et al., 1987). The isotopic signature of the sedimentary carbon has been shown to be preserved in shallow subsurface sediments that are less than 100 yr old by Chmura et al. (1985) and DeLaune (1986) and possibly in much older sediments studied by Emery et al. (1967). Over time, however, it is possible that the sedimentary  $\delta^{13}\text{C}$  value could be shifted by decomposition or other diagenetic processes, to the point where it is no longer characteristic of the original sources. In some environments there is a potential that carbon sources of the vascular plants could be diluted by other autochthonous sources (such as benthic algae, diatoms, phytoplankton and bacteria) which have  $\delta^{13}\text{C}$  values uncharacteristic of the vascular plant community. The  $\delta^{13}\text{C}$  value of the higher plant community could also be diluted by allochthonous carbon sources.

Discriminant functions have been developed which can distinguish four vegetation zones within the modern Barataria Basin marshes: fresh, intermediate, brackish and salt. In ancient marshes, however, processes of water transport, as well as sources of regional and local pollen may differ from those of modern Barataria Basin marshes, causing pollen assemblages within these salinity zones to have different characteristics.

The objective of this study is to test the applicability of both  $\delta^{13}\text{C}$  and palynological analyses on older, buried marsh sediments of the Mississippi delta plain. The validity of the isotopic and palynological signatures is determined by comparing the results of both techniques within the stratigraphic context of the deposit.

#### REGIONAL GEOLOGY OF THE STUDY AREA

The core site is within Terrebonne Parish which lies within the south-central region of the Mississippi delta plain (Fig. 1). Studies of the dynamic changes and processes in the Mississippi River delta have been reviewed by Coleman (1988). Construction of the modern delta plain of the river began by 9,000 yr B.P. The delta plain has been shaped by a process of sequential episodes of building and abandonment of individual delta lobes which have been described and dated by Coleman and Gagliano (1964), Fisk (1944), Frazier (1967), Kolb and Van Lopik (1958) and Scruton (1960) (figure 2). During the building phase, termed "constructional", "progradational" or "regressive", distributaries rapidly prograde seaward and sediments fill the shallow interdistributary bays. These bays normally receive a fine-grained suspended load only during high floods or through small breaks in channel banks which form overbank splays. Overbank splays may be active about 10-15 yr over an area of 12 to 15 sq km and result in a sedimentary sequence approximately 3 m thick. Bay filling occurs on a larger scale, over an area of 10 to 15 km wide and 20 to 25 km long and requires 100 to 150 yr to form stacked units approximately 5 to 20 m thick. These deposits are characterized by a sedimentary sequence consisting of shallow marine bay clays and marsh peats. Proximal to the original channel break earlier depositional cycles may be eroded, but in central and more distal parts of the bay fill the cycle may begin with a marine clay or marsh peat which represents the original surface of the bay bottom or the old marsh surface that has subsided below sea level (Coleman 1988).

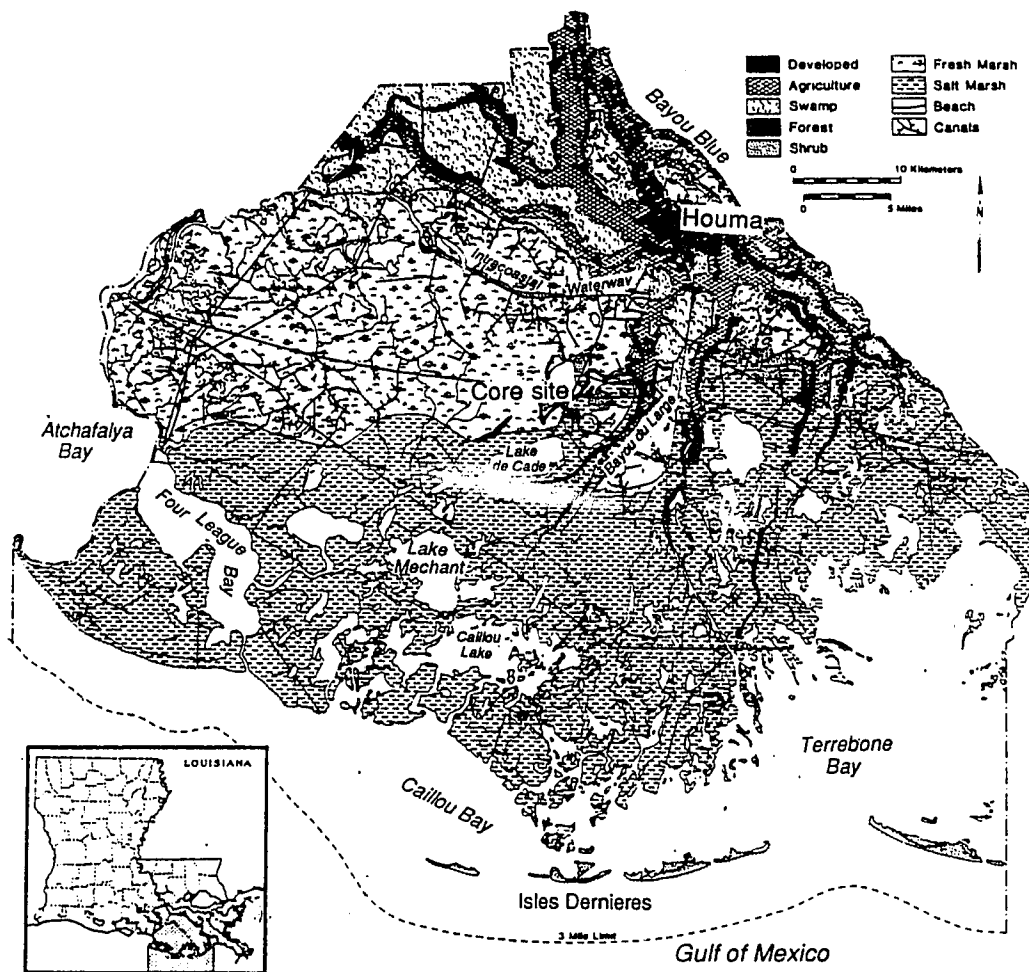


FIG. 1. Location map for core site, Terrebonne Parish, Louisiana (adapted from Penland et al. 1988 and Wicker et al. 1980).

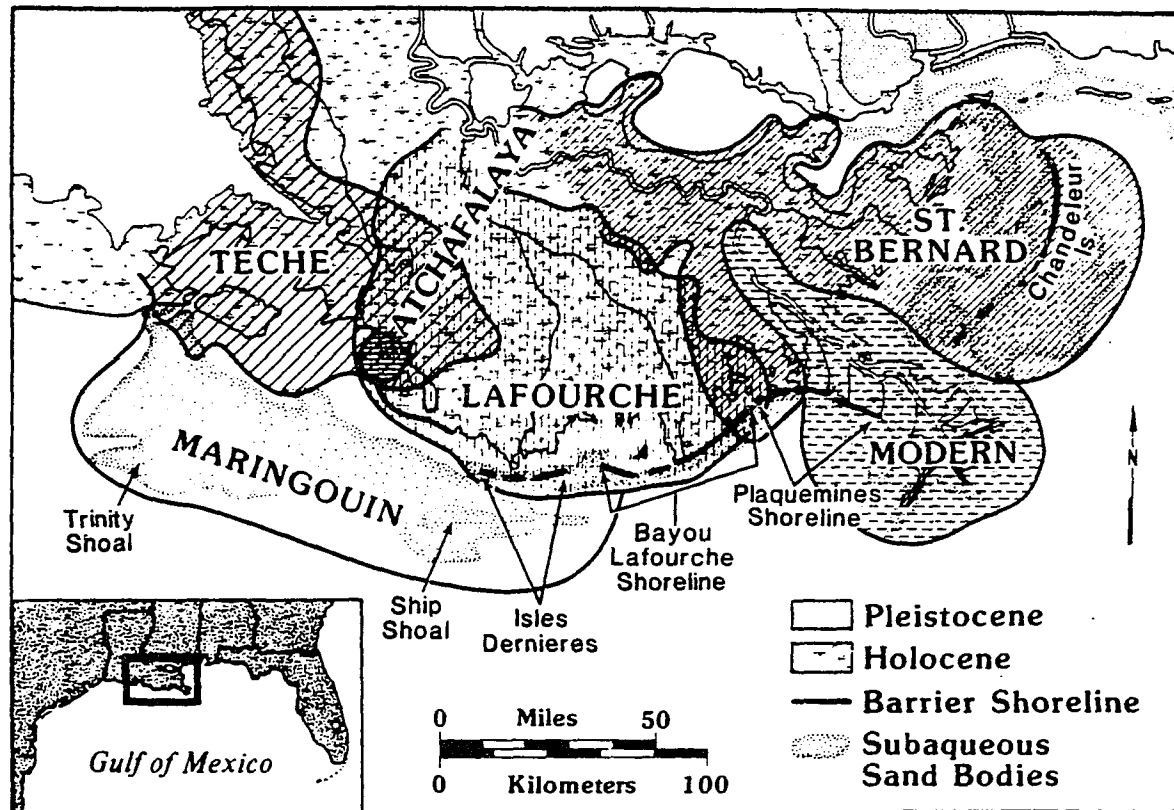


FIG. 2. Deltaic lobes of the Mississippi river deltas. (Reprinted from Penland et al. 1988, adapted from figure 1, Frazier 1967:289.)

As river gradients become less favorable a new distributary channel will become active and a new locus of deposition is created (the "delta switching" process) causing sedimentation from this distributary to eventually cease. This marks the beginning of the abandonment phase, also termed the "transgressive" or "destructive" phase. The transgressive phase is marked by subsidence of the marsh which caps the constructive sequence. In some instances, the cycle is also capped by a thin transgressive sand deposit, which represents local reworking of the earlier cycle, and concentration of sand and shell in a thin beach deposit. These beach deposits are not common because of the lack of intense wave reworking and rapidity at which the process from regression to abandonment takes place (Coleman 1988).

Subsurface geology of the south-central delta plain has been studied by Penland et al. (1988), Roberts (1985) and Smith et al. (1985). In the Terrebonne Parish area the delta plain consists of three abandoned delta complexes, the Maringouin/Sale Cypremort, the Teche, and the Lafourche (Figure 2). The Lafourche delta complex built from 300 to 2490 yr B.P. during a period when sea level was relatively stable. It is made up of four individual deltas which, in order of increasing age are: Bayou du Large, Bayou Terrebonne, Bayou Grand Caillou and Bayou Lafourche (figures 3 and 4).

#### METHODS

The core was taken in an area of saltmarsh (vegetated with *Spartina patens*) on the north side of Falgout Canal 1 km west of Bayou du Large (figure 1) with a vibracorer employing a 7.5-cm diameter pipe. Approximately 5.3 m were retrieved with a compaction of 133 cm, which is assumed to be concentrated in the water-rich upper 2 m. The core was brought to the Louisiana Geological Survey Coastal Geology Program Laboratory where it was split and the stratigraphy was described. Samples were then removed for  $^{14}\text{C}$ -dating,  $\delta^{13}\text{C}$  analyses and palynological concentration.

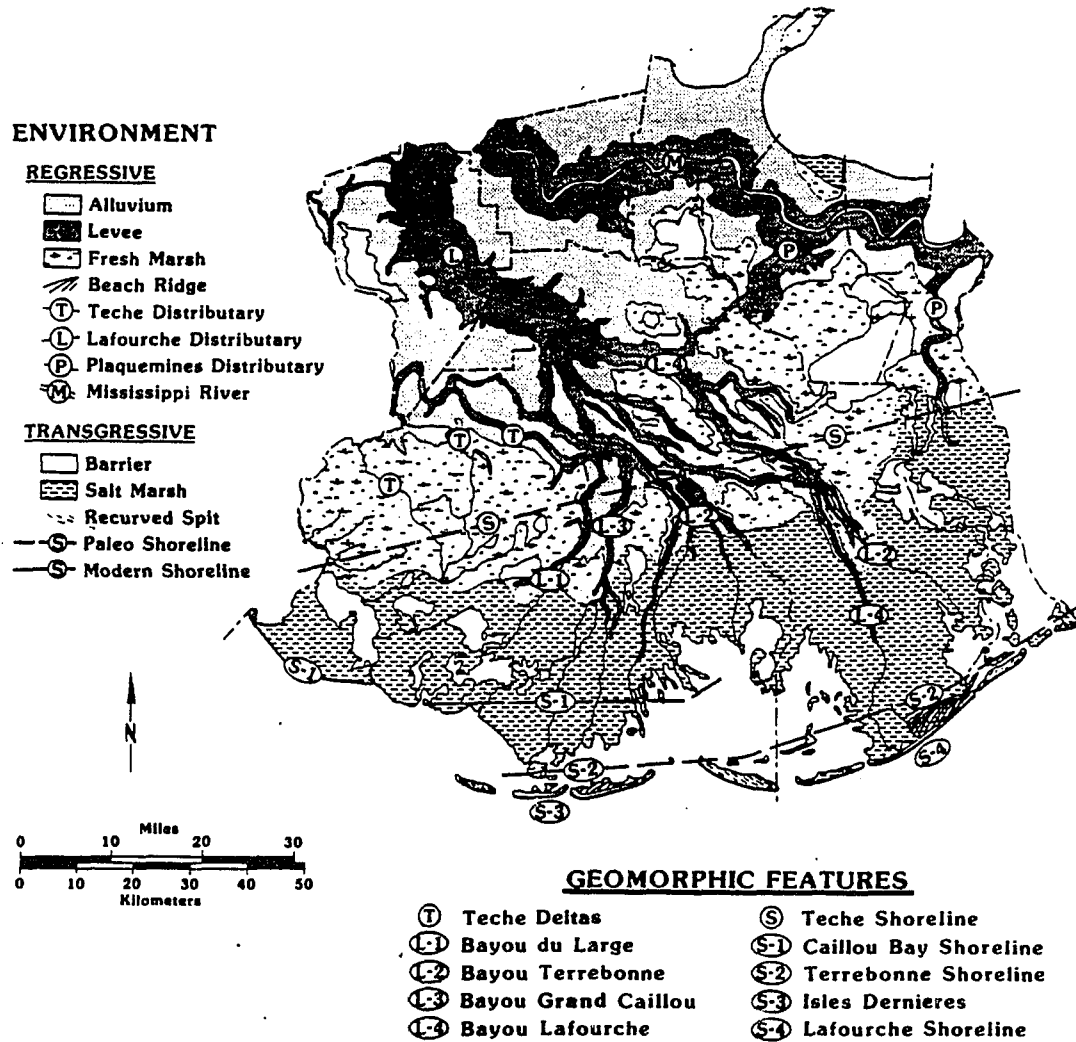


FIG. 3. Geomorphologic diagram of the Teche and Lafourche delta complexes in the Terrebonne Parish region. (Reprinted from Penland et al., 1987, redrawn and adapted from Chabreck and Linscombe 1978 and Snead and McCulloh 1984.)

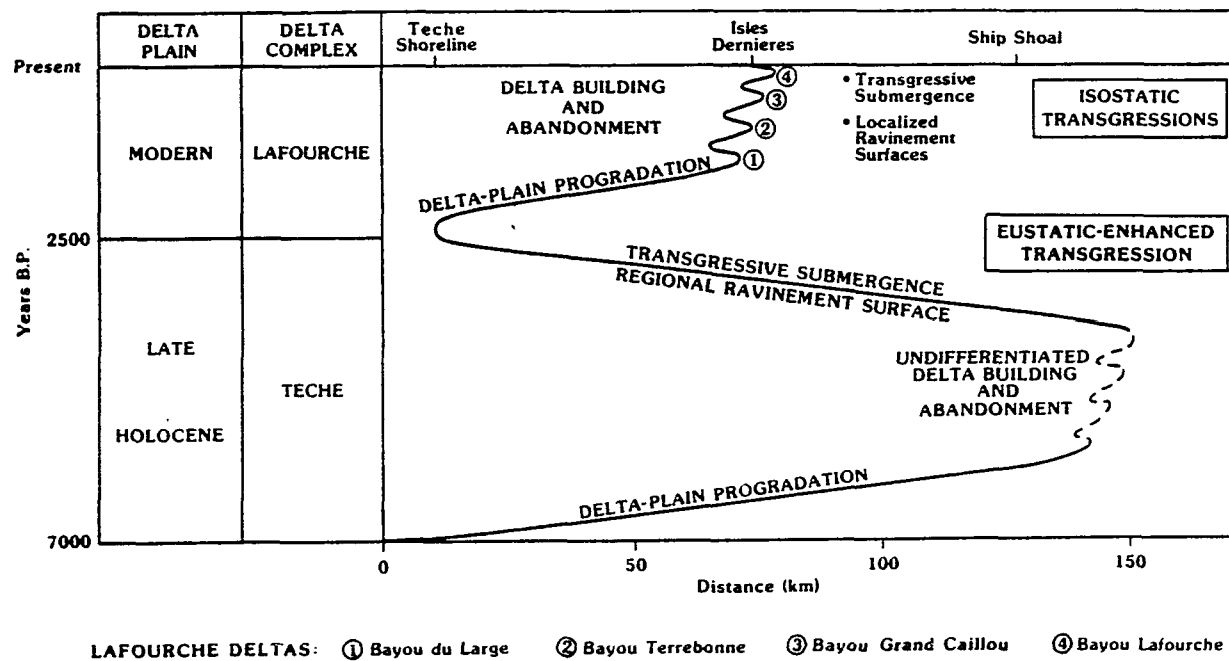


FIG. 4. A chronostratigraphic model depicting the development of the Terrebonne coastal region as a function of sea level changes and sediment supply. (Reprinted from Penland et al., 1987.)

Radiocarbon dating was performed at the laboratory of Krueger Enterprises on a sample of *in situ* peat taken from a depth of 314-324 cm. Samples for stable isotope and palynomorph counting were taken from 210 to 500 cm from sections representing marsh deposits, as indicated by high organic contents and rooting. Samples were processed and analyzed for  $\delta^{13}\text{C}$  as described by Chmura et al. (1987) and for palynomorph study as described in Chapter 3.

All palynomorph percentages are based on a sum which includes all taxa except those which are important constituents of Mississippi River flood waters: *Pinus*, *Quercus*, *Taxodium*, TCT, *Ambrosia* and Chenopodiaceae-Amaranthaceae types (Chapters 2 and 3). Pollen assemblages were classified by discriminant functions developed with surface marsh samples from Barataria Basin, Louisiana (Chapter 3) using the subprogram DISCRIMINANT in SPSSX (Statistical Package for the Social Sciences 1988). Taxa used as discriminant variables correspond to common taxa occurring within the coastal marshes: Gramineae, Compositae-Tubuliflorae type, Cyperaceae, *Myrica*, *Vigna*, *Osmunda*, Polypodiaceae, *Sagittaria*, *Typha angustifolia* type and *Typha latifolia* type. The combined percentages of these groups do not add up to 100% in any sample. Probability of modern analogue is calculated for each sample as described by Liu and Lam (1985).

## RESULTS AND DISCUSSION

### *Stratigraphy*

An organic rich, rooted deposit exists from 500 to 487 cm, with organic content decreasing upwards (figure 5). At 487 cm there is an abrupt transition to a non-rooted clay. Because of its fine grain size and thickness this deposit is assumed to be of fluvial origin, perhaps representing the initial stage of splay or sub-delta development. This deposit continues to 464 cm when the large influx of fine-grained clastics considerably decreased, again allowing organic accumulation to predominate. From



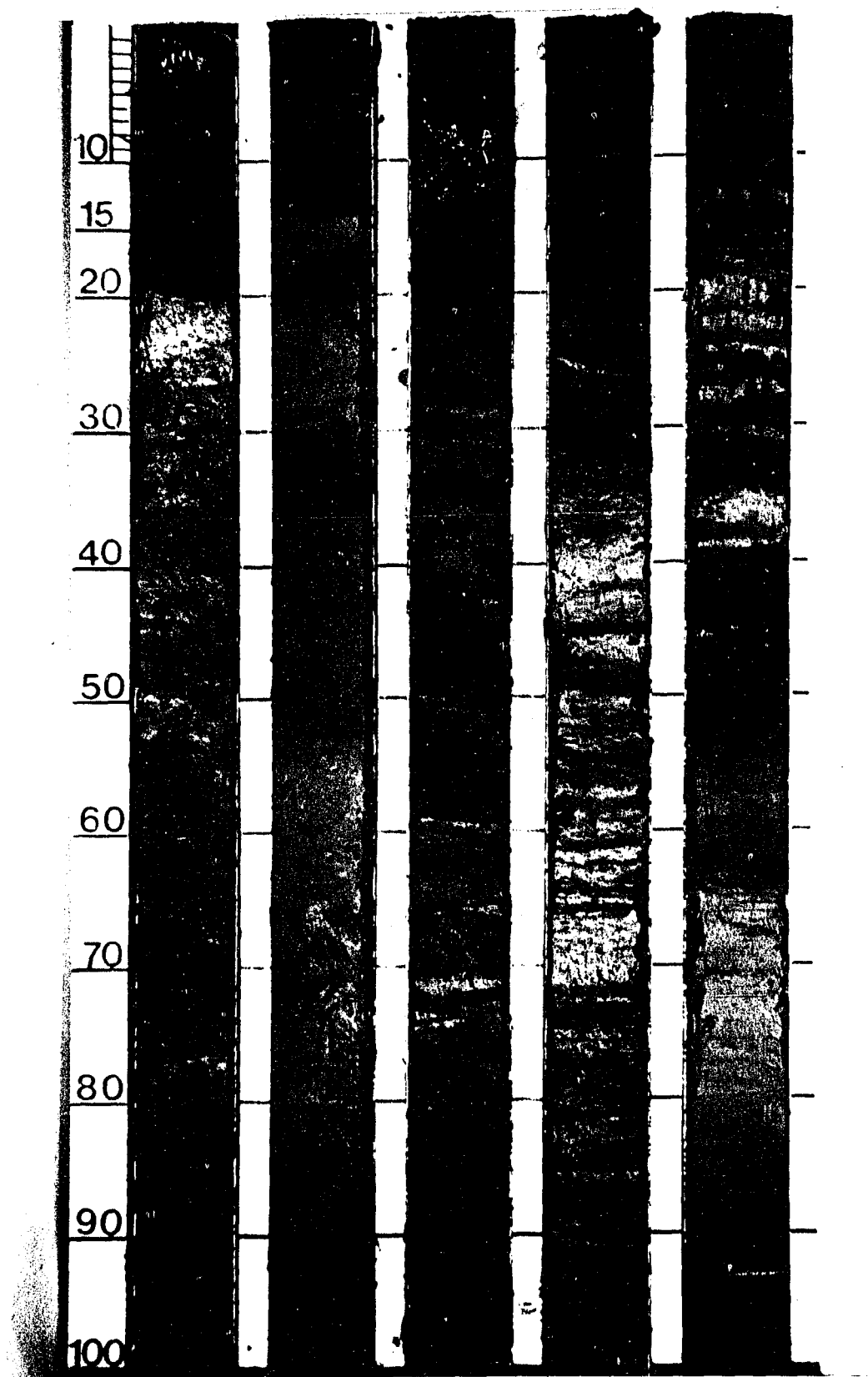


Fig. 5. Photograph of Falgout Canal core. Vertical scale in cm. Depth increases from top to bottom, left to right.

this level to 440 cm sediment ranges from organic-rich to organic-poor, and in the upper 10 cm (450-440 cm) incorporates 0.5 to 1-cm diameter plant fragments.

The next section extends to 342 cm and contains organic-rich and poor layers, 1 to 50 mm thick, alternating with rooted clay layers which also range in thickness from 1 to 50 mm. Such layering of clastic and organic deposits could be the result of frequent storm deposits or river-flood deposits (Baumann et al. 1984 and Rejmánek et al. 1988).

From 342 to 304 cm organic accumulation again became dominant, resulting in a rooted organic-rich section. Alternating layers of clastic and organic material occur above 304 cm, similar to that occurring deeper in the core. The clastics, however, coarsen upwards from clay to silt and finally, sand at the top of the section. The increased coarseness of clastics relates to increasing hydraulic energy and submergence of the deposit. The section is capped by a 6-cm thick layer of shell hash at a depth 212 cm. The stratigraphy indicates that section 210 to 440 cm generally represents a marsh environment during a period of progradation (above the clay beds of an open bay topping a subsided marsh from a previous cycle) followed by predominantly organic accretion, then subsidence, or a transgressive phase. The age of the deposit within the section 314 to 324 cm is  $1720 \pm 140$  yr B.P. Thus this progradational and transgressive episodes of this core section probably correspond to the progradation of Bayou du Large during the construction of the Lafourche delta complex (figure 4).

Above 206 cm, to approximately 90 cm, are alternating beds of rooted clays and organic layers which contain detrital plant fragments. Within this section are two beds of fine-grained sand at 120 and 150 cm. The core is topped by a rooted organic rich deposit.

### *$\delta^{13}C$ Analyses*

All isotope results are reported in conventional delta ( $\delta$ ) notation in per mil relative to the international standard PDB according to Craig (1957). Values of  $\delta^{13}C$  range

from -21.07 to -14.61‰ (PDB) (table 1, figure 6). These values span the ranges characteristic of intermediate (-25.0 to -18.4‰, PDB) as well as brackish and salt marshes (-20.4 to -14.4‰, PDB), as described by Chmura et. al. (1987). This indicates that the proportion of C-4 plants increased from 444 cm to 434 cm, decreased around 405 cm and then steadily increased during deposition of the remaining section to 210 cm. From 500 to 307 cm  $\delta^{13}\text{C}$  values fluctuate between intermediate and brackish/salt values, then increase to values within the brackish/salt marsh range at depths above 307 cm.

### *Palynomorphs*

Micro-foraminifera are present at all but the lowermost depth sampled, 494 cm (table 2). Since forams were not found in surface fresh marsh samples (Chapter 3), their presence in this core indicates that salinities of the remaining paleomarch environments were higher (or subject to more tidal influx) than that of modern fresh marshes with the Barataria Basin.

A total of 58 pollen and spore types were identified. Percentages (based on a sum of pollen and spores minus major river components) of the most abundant types are shown in figure 6. Counts of all samples are provided in Appendix 2. Gramineae is the major pollen type found throughout the profile (figure 6). Other abundant forms are Cyperaceae, Chenopodiaceae-Amaranthaceae and TCT types. Found in lesser abundance, but still common are *Ambrosia*-type, *Quercus*, *Pinus*, *Fraxinus*, *Taxodium*. Polypodiaceae type spores were poorly represented, only once exceeding 2%. *Osmunda* spores were limited to the occurrence of single grains within any sample.

Assemblages of the 10 taxa used in the discriminant analysis are classified as one of four vegetation zones by the discriminant functions developed for surface marsh samples (Table 1). Each assemblage is discussed below within the stratigraphic context of the core section.

*Transgressive phase I (500-464 cm)*

Salt marsh zone - The  $\delta^{13}\text{C}$  value at the sample depth 494 cm is within a range which does not distinguish between intermediate or brackish/salt, but pollen analysis suggests that this organic material was deposited in a saline environment. There is an absence of many fresh marsh indicators such as fern spores, *Vigna*, *Decodon* and *Taxodium*, as well as indicators of the intermediate zone such as *Bacopa*, *Polygonum* and *Sagittaria*. The percentage of Gramineae is high (52% ) and *Typha angustifolia* type is greater than 9%.

*Progradational phase (464-342 cm)*

The progradational phase is characterized by the highest percentages of extra-regional types (*Quercus*, *Pinus* and *Ambrosia*) in the core sections analyzed. The highest percentages of *Salix*, Compositae-Tubuliflorae type and *Fraxinus* also occur within this phase. Percentages of extra-local indicators vary considerably, indicating that marsh community structure changed during this period.

Salt marsh zone - Percentages of Gramineae and Cyperaceae are close (35 and 30%, respectively). This relatively high percentage of Cyperaceae would suggest an intermediate marsh except for the absence of indicators such as *Bacopa*, *Sagittaria* and *Polygonum*. The extra-regional taxa *Quercus*, *Pinus* and *Ambrosia* are all low. The presence of 5% *Typha angustifolia* type and low percentage of Compositae-Tubuliflorae type are factors which cause it to be classified as salt marsh.

Intermediate marsh zone - The percentage of Cyperaceae increases to 76% and Gramineae is considerably reduced (14%). Neither *Vigna* nor *Salix* are present.

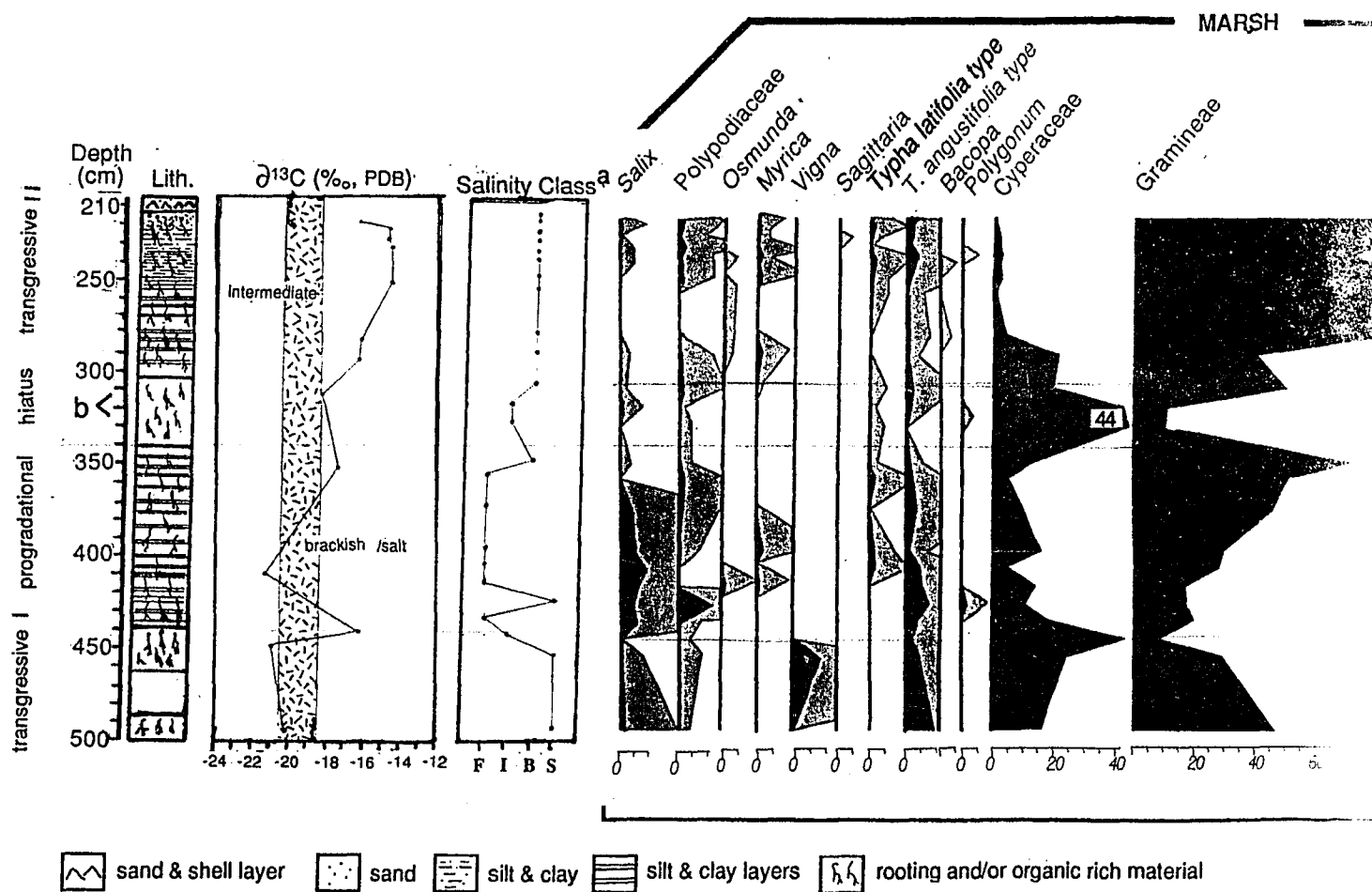
Fresh marsh zone - Percentages of Cyperaceae and Gramineae are equal (20%) with 6% Compositae-Tubuliflorae type. The  $\delta^{13}\text{C}$  value of -16.2‰ would classify the vegetation zone as a brackish/salt marsh community.

Table 1. Prediction of vegetation zones and probability of modern analogues, based on discriminant analysis classification of surface marsh samples (chapter 3) and corresponding  $\delta^{13}\text{C}$  values of samples from Falgout Canal core.

sample number	depth cm	$\delta^{13}\text{C}$ ‰	predicted zone	probability %
24	214	-16.4	brackish	31.40
23	217	-14.8	brackish	41.66
22	223	-14.8	brackish	24.54
21	228	-14.6	brackish	30.62
20	234		brackish	7.31
19	238		brackish	23.53
18	247	-14.6	brackish	64.41
17	254		brackish	21.95
16	278	-16.3	brackish	26.10
15	289	-16.4	brackish	4.40
14	307	-18.3	brackish	26.72
13	317		intermediate	98.50
12	328		intermediate	47.78
11	348	-17.5	brackish	71.51
10	356		fresh	40.45
9	373		fresh	11.17
8	396		fresh	1.37
7	405	-21.1	fresh	0.07
6	415		fresh	0.00
5	425		salt	0.01
4	434	-16.2	fresh	0.35
3	444	-20.9	intermediate	75.96
2	454		salt	0.54
1	494	-20.1	salt	89.35

# FALGOUT CANAL CORE, TERREBONE PARISH, LOUISIANA

Analyst G.L. Chmur



<sup>a</sup>F=fresh, I=intermediate, B=brackish, S=salt as determined by discriminant analyses classification described in text.

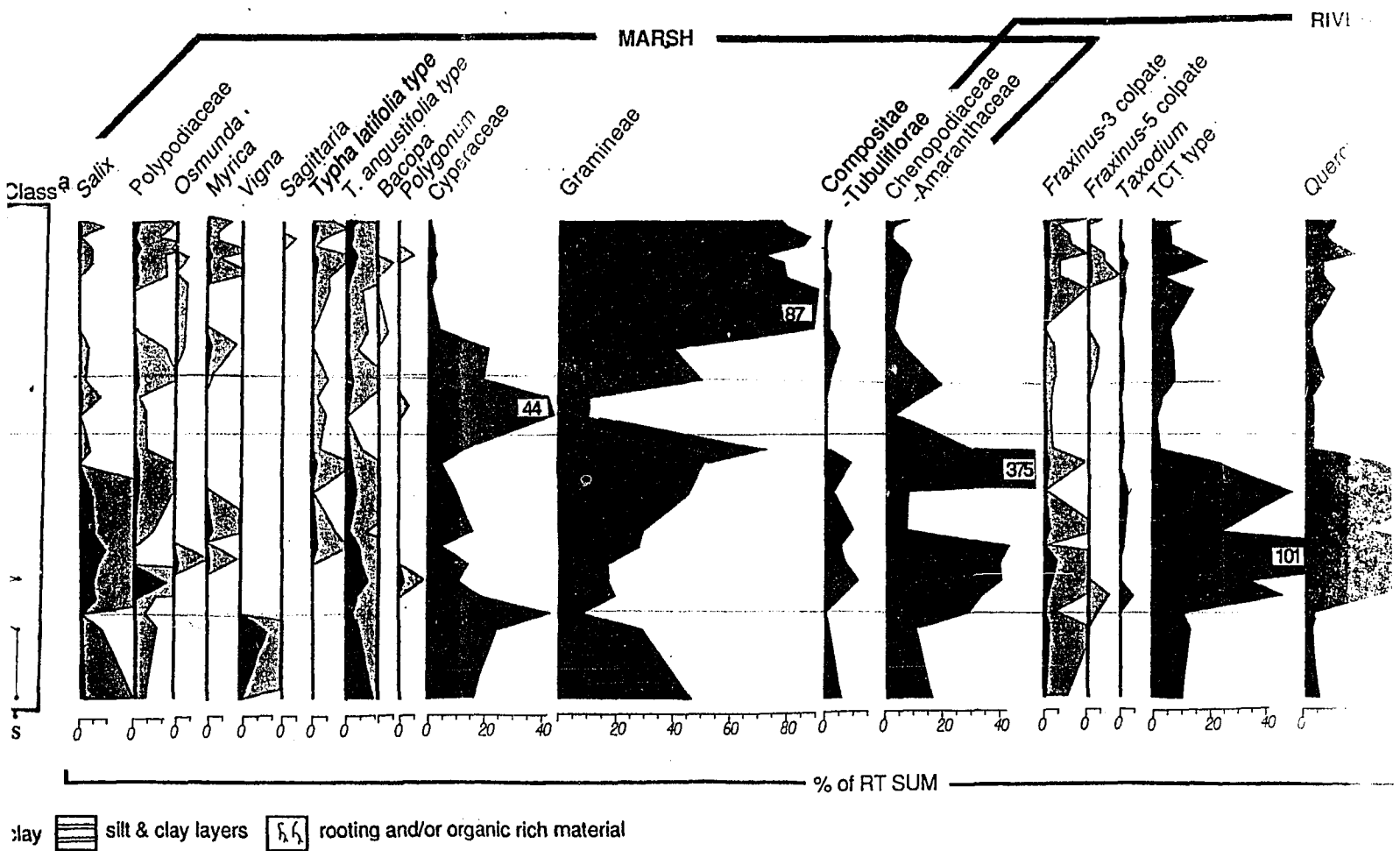
<sup>b</sup>Section 3

FIG. 6. Pollen,  $\delta^{13}C$  and salinity class profiles of Falgout Canal Core. Grey area represents 10% exaggeration. Comp.



# ONE PARISH, LOUISIANA

Analyst G.L. Chmura 1989



determined by discriminant analyses classification described in text.

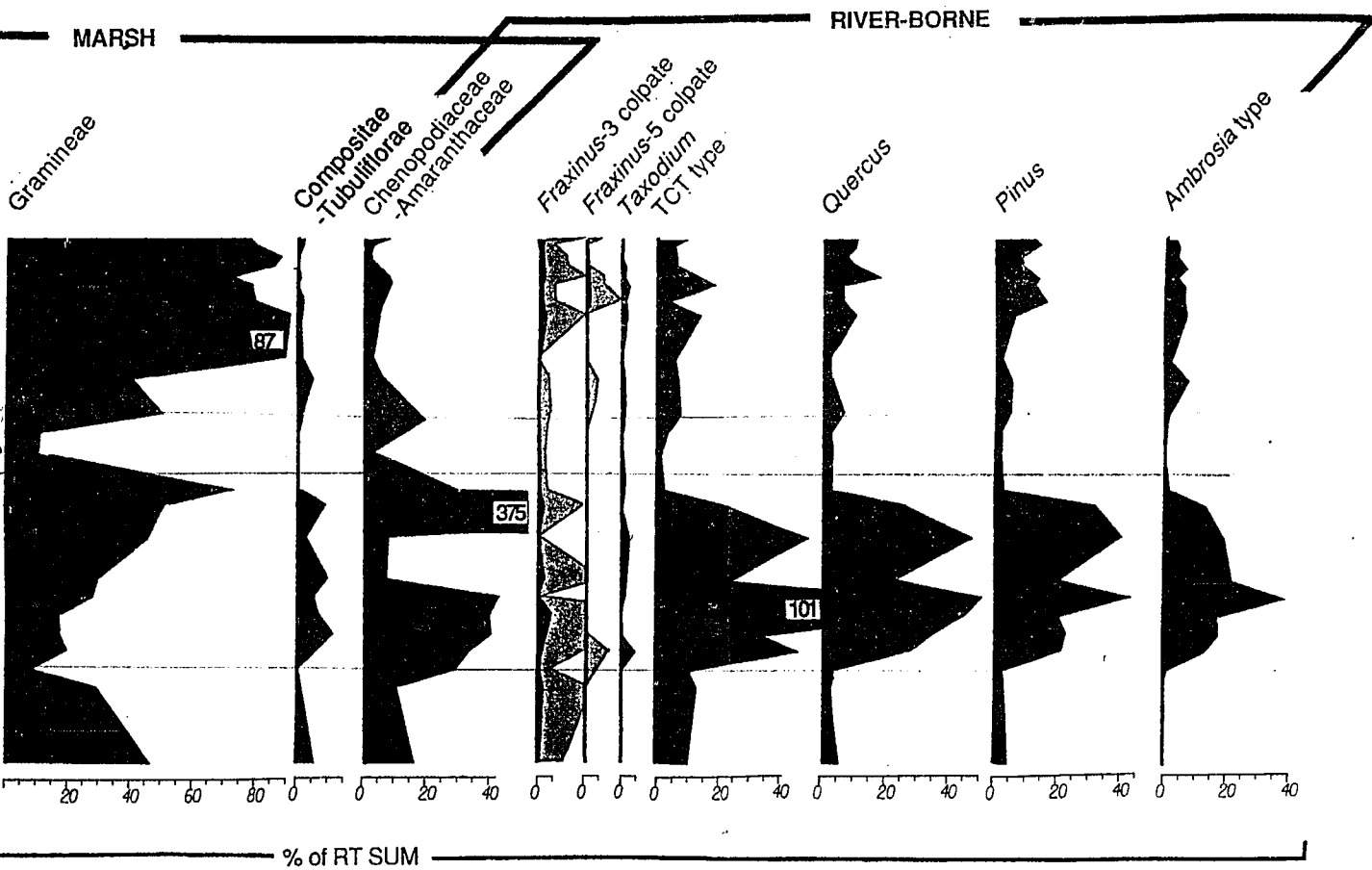
<sup>b</sup>Section 314 to 324 cm radiocarbon dated 1720 ±140 yr B.P.

es of Falgout Canal Core. Grey area represents 10% exaggeration. Computation of sum explained in text.





analyst G.L. Chmura 1989



material

ed in text. <sup>b</sup>Section 314 to 324 cm radiocarbon dated 1720  $\pm$ 140 yr B.P.

exaggeration. Computation of sum explained in text.



Table 2. Microforaminifera in samples from Falgout Canal core.

depth cm	Microforaminifera	
	number counted	number per cc
214	5	945
217	1	149
223	10	4654
228	6	14520
234	8	13829
238	5	2750
247	6	6600
254	6	3457
278	4	621
289	5	786
307	3	844
317	10	5261
328	3	1815
348	1	327
356	5	2521
373	12	4840
396	28	9411
405	26	5826
415	12	1252
425	40	4792
434	31	4519
444	1	161
454	13	2313
494	0	0

Salt marsh zone - Values of Cyperaceae (11%) and Gramineae (17%) decrease from 434 cm. Percentages of Compositae-Tubuliflorae type, Polypodiaceae, and *Typha angustifolia* type are increased (12, 12, and 7%, respectively).

Fresh marsh zone - Gramineae percentages increase from 17 to greater than 33% within this fresh marsh section. Percentages of *Typha angustifolia*, Compositae-Tubuliflorae and Polypodiaceae types are decreased from lower sections. The presence of *Myrica* and *Osmunda* are important in causing these assemblages to be classified as fresh marsh. The  $\delta^{13}\text{C}$  value of -21.1‰ at 405 cm would classify that sample as intermediate marsh.

#### *Hiatus phase (342-304 cm)*

Brackish marsh zone - Percentages of Gramineae (78%) are more than double that of the fresh marsh of the lower depth. Cyperaceae increases, but there is no Compositae-Tubuliflorae type or Polypodiaceae, and only 1% *Typha angustifolia* type. The classification is supported by the  $\delta^{13}\text{C}$  value of -17.5‰ which is in the brackish/salt range.

Intermediate marsh zone - Pollen assemblages are dominated by Cyperaceae ( $\geq 71\%$ ) with lesser amounts of Gramineae.

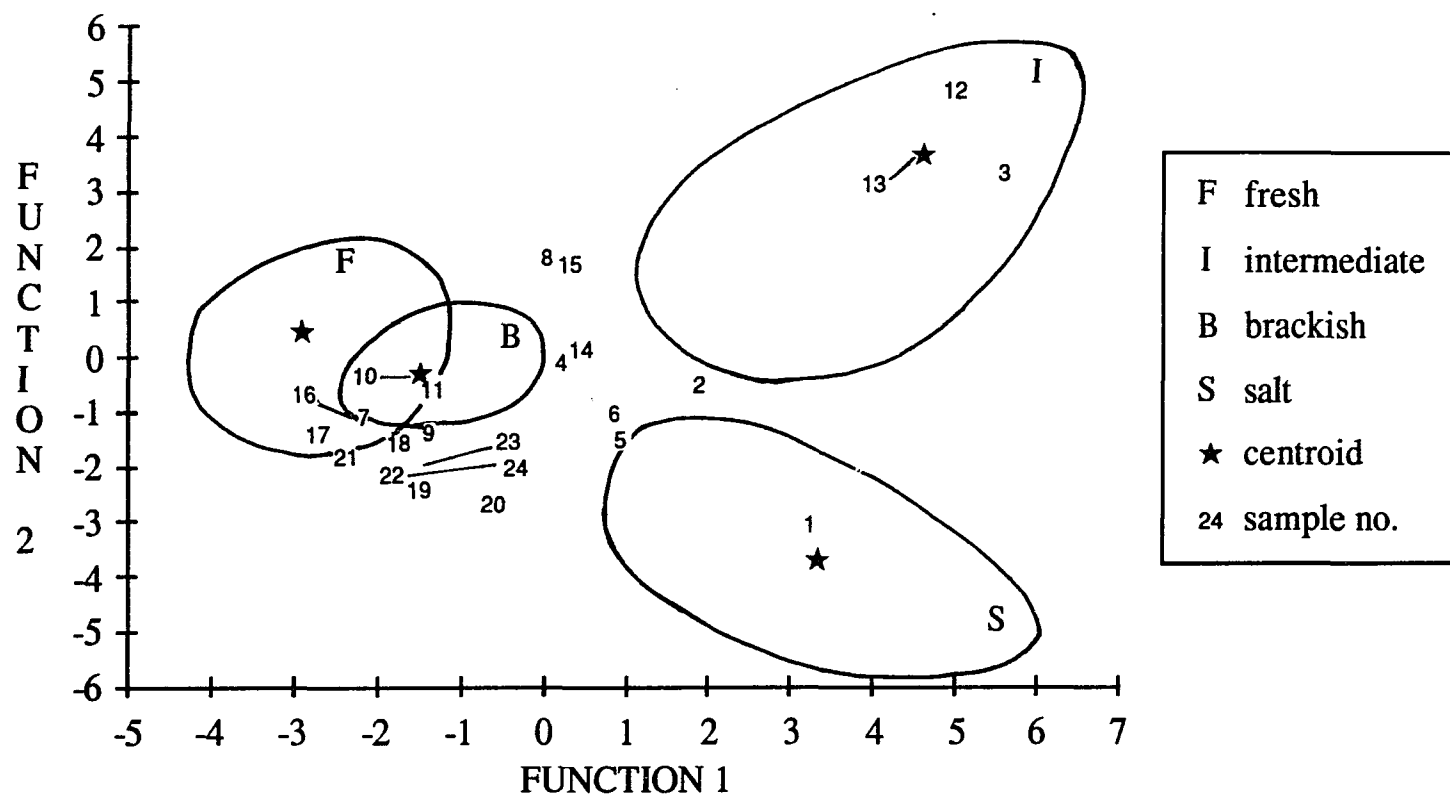
#### *Transgressive phase II (304-210 cm)*

Brackish marsh zone - The Cyperaceae percentage shows a general increase from 23% (less than one-third of the amount present in the lower intermediate marsh zone). Gramineae shows a reciprocal increase, starting at 58%. There is only a minor occurrence of Cyperaceae, Compositae-Tubuliflorae type, Polypodiaceae, *Myrica* and *Typha angustifolia* type.

### *Alternative analogues*

Although in 11 of 13 cases the results from  $\delta^{13}\text{C}$  and palynological classification agree as to salinity zone there is evidence to suggest that many of the environments classified are not comparable to the modern environments upon which the classification schemes are based. Both the stratigraphy and pollen assemblages indicate that the section from 440 to 340 cm represents a progradational phase, in this case flooding into an area of actively accreting marsh deposits. Percentages of non-marsh species such as TCT type, *Quercus*, *Pinus*, *Ambrosia* type, *Fraxinus*, *Salix* and *Taxodium*, as well as Chenopodiaceae-Amaranthaceae type increase in this section. *Quercus*, *Pinus*, Chenopodiaceae-Amaranthaceae, TCT, and *Ambrosia* type have been identified as major components of the pollen assemblage of the Mississippi River during flood stage (Chapter 2). *Fraxinus*, *Salix*, *Taxodium* and TCT type are not major constituents of the modern pollen assemblage in Mississippi River waters but represent dominant elements of bottomland hardwood and cypress swamp communities. Both were considerably more extensive in the Mississippi alluvial valley before timber harvesting which occurred in the last two centuries. It is likely that these pollen types would have been more abundant in river flood waters during earlier times.

In figure 7 the scores from discriminant functions 1 and 2 of the core samples are plotted along with the boundaries of the Barataria Basin marsh vegetation groups. Of the 24 samples classified 15 fall out of the boundaries of any of the four groups. Probabilities of modern analogue for these samples are correspondingly low (Table 1) indicating that an appropriate analogue for those environments was not included in the samples used for development of the classification (Liu and Lam 1985).



Research on vegetation communities of progradational marsh areas has not been as extensive as that carried out on the upper delta plain, but the limited studies do show that there are marked differences among the communities. O'Neil (1949), however, provides a qualitative description of vegetation zones associated with progradational environments of the lower delta (Table 3). If a broad assumption is made that sedimentary carbon is composed of equal parts of each species, a  $\delta^{13}\text{C}$  value for these three zones can be estimated (Table 3). Both O'Neil's "new natural levee zone" and "old natural levee zone" would have  $\delta^{13}\text{C}$  values in the range of intermediate marsh (Chmura et al. 1987). This could be one explanation for the conflict in classification of the sample at 405 cm which has a  $\delta^{13}\text{C}$  value of  $-21.1\text{‰}$ , but is classified, on the basis of palynological analysis, as fresh marsh. Local pollen sources would primarily be Gramineae and *Typha*, both are well represented at this level. Making the same assumption to estimate the  $\delta^{13}\text{C}$  of O'Neil's "delta sub-transitional zone" shows that it could have a  $\delta^{13}\text{C}$  in the range of brackish and salt marsh (Table 3). The sample from 434 cm has a  $\delta^{13}\text{C}$  value in this range ( $-16.2\text{‰}$ ), but is classified as fresh marsh. Pollen of *Juncus* is generally not preserved, thus is not useful in characterizing this assemblage. An analogue for this pollen assemblage does not exist in the suite of classified samples. More detailed descriptions of vegetation occurring in the newest delta of the Mississippi, the Atchafalaya delta, have been published by Johnson et al. (1985), Shaffer et al. (1988), Evers et al. (1988) and Visser (1989). Vegetation established on newly formed islands in the Atchafalaya River delta included *Salix nigra*, *Sagittaria latifolia*, *Mikania scandens*, *Justica ovata*, *Scirpus validus*, *Scirpus americana*, *Sphenoclea zeylanica*, *Ammania coccinea*, and *Typha domingensis* (Johnson et al. 1985 and Shaffer et al. 1988). After approximately nine years and deposition of 9 cm of sediment from a major flood in 1983 vegetation diversity increased to include species such as *Leersia oryzoides*, *Polygonum punctatum*, *Colcasia esculenta*, *Vigna luteola*, and *Echinochloa spp.* (Shaffer et al. 1988). In areas



TABLE 3. Carbon-13 values of species found in lower delta plain marshes as described by O'Neil (1949).

species	$\delta^{13}\text{C}$ , ‰ PDB	
	min	max
"new natural levee zone"		
<i>Scirpus americanus</i> <sup>9</sup>	-26.0	-30.5
<i>Typha</i> sp. <sup>4,12</sup>	-25.2	-27.6
<i>Spartina alterniflora</i> <sup>7,11</sup>	-12.1	-15.5
avg	-21.1	-24.5
"old natural levee zone"		
<i>Spartina alterniflora</i>	-12.1	-15.5
<i>Typha</i> sp.	-25.2	-27.6
<i>Phragmites australis</i> <sup>4, 12, 14</sup>	-24.6	-29.4
avg	-20.6	-24.2
"delta sub-transitional zone"		
<i>Spartina alterniflora</i>	-12.1	-15.5
<i>Spartina patens</i> <sup>2,5</sup>	-11.7	-13.6
<i>Juncus roemerianus</i> <sup>3,6,8,9,10</sup>	-22.8	-26.0
<i>Distichlis spicata</i> <sup>1,3,13</sup>	-12.8	-14.7
avg	-14.9	-17.4

<sup>1</sup>Bjorkman and Gauhl 1969, <sup>2</sup>Chmura et al. 1987, <sup>3</sup>Craft et al. 1988, <sup>4</sup>DeNiro and Hastorf 1985, <sup>5</sup>Emery et al. 1967, <sup>6</sup>Hackney and Haines 1980, <sup>7</sup>Haines 1976, <sup>8</sup>Haines and Montague 1979, <sup>9</sup>Hughes and Sherr 1983, <sup>10</sup>Johnson and Calder 1973, <sup>11</sup>Sackett 1986, <sup>12</sup>Smith and Brown 1973, <sup>13</sup>Smith and Epstein 1971, <sup>14</sup>Troughton et al. 1974

where exclosures had been constructed to prevent herbivory by nutria (*Myocastor coypus*) and muskrat (*Ondatra zibethicus*) a considerable decrease was noted in abundances of *Sagittaria* with a corresponding increase in *Justica ovata* and other species (Evers et al. 1988 and Visser 1988). Since nutria is an exotic species and muskrat populations were probably negligible before European settlement (O'Neil 1949) it is possible that *Sagittaria* was a much more ephemeral member of fresh and intermediate marshes of the upper delta plain in pre-settlement time. These findings, and the observation that there is a limited occurrence of *Sagittaria* in the entire section of core studied suggest that the source of this pollen type (which is an important discriminating taxon) may have been considerably reduced, if not absent in paleomarch communities. Another pollen type with an occurrence which does not correspond to the analogues provided in Chapter 3 is *Typha angustifolia* type, assumed to be locally represented by *T. domingensis*. This type is relatively well represented throughout the core section studied, regardless of  $\delta^{13}\text{C}$  values and *Typha* (assumed to be *T. domingensis*) is a common component of progradational marshes (O'Neil 1949, Johnson et al. 1985, Shaffer et al. 1988).

#### CONCLUSIONS AND RECOMMENDATIONS

Both  $\delta^{13}\text{C}$  and palynological analyses can detect changes in vegetation composition in material up to approximately 2,000 yr old. The  $\delta^{13}\text{C}$  of sedimentary carbon can be explained within the context of the stratigraphy and pollen assemblages, thus it is assumed that diagenetic processes have not caused a significant shift in the original  $\delta^{13}\text{C}$  value over this period of time. Although important analogues are missing the combination of the two techniques within the stratigraphic context can provide information regarding paleomarch vegetation.

Fossil pollen assemblages may have a low probability of modern analogue simply because they represent transitional vegetational communities (Liu and Lam 1985), for

example, those changing from one salinity zone to another. With high resolution sampling it may be possible to detect a systematic shift in modern analogue probabilities which reflect this change. Corresponding  $\delta^{13}\text{C}$  values should demonstrate a similar shift. In this study the sampling intensity was not great enough to make determinations regarding the presence of transitional communities.

The suite of modern samples provided as an analogue for  $\delta^{13}\text{C}$  and palynological signatures, however, is not extensive enough. Additional studies are required to include progradational marsh types such as Atchafalaya delta island marshes and marshes of crevasse splays of the lower delta plain. More samples should also be added to each vegetation zone to reflect transitional areas as well as to strengthen the power of the classification performed by discriminant analysis of palynomorph assemblages.

Successful palynological separation of the Gramineae taxa *Spartina alterniflora*, *Spartina patens* and *Phragmites australis* has been reported by Clark and Patterson (1985). If this is possible for important taxa in the Mississippi delta plain, then it could serve as an additional powerful discriminator among Barataria Basin and progradational marsh types.

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## SYNTHESIS AND CONCLUSIONS

Palynological and carbon isotopic techniques can be useful tools for reconstruction of paleomarch salinity zones. When used together within a stratigraphic context these methods provide a sensitive indicator of marsh plant community zones, which correspond to salinity zones of the Mississippi delta plain marshes.

The  $\delta^{13}\text{C}$  of the sedimentary carbon reflects the proportion of C-3 and C-4 species in a marsh community. Within the coastal marshes of the Mississippi delta plain the proportion of C-4 species increases with increasing salinity. Thus, the  $\delta^{13}\text{C}$  also serves as an indicator of salinity. Brackish and salt marsh zones cannot be distinguished with this method because the vegetation communities of both are composed predominantly of C-4 species. A second limitation is an overlap of  $\delta^{13}\text{C}$  ranges between intermediate and brackish/salt marsh sedimentary carbon. Fractionation of plant carbon during early diagenesis would be expected to result in more negative  $\delta^{13}\text{C}$  values as the more refractory material is depleted in  $^{13}\text{C}$  with respect to whole plant carbon. In fact, in brackish and salt marshes where decomposition is greater there is a slight shift to more depleted values. Marsh sediments as old as 1720 yr B.P., however, demonstrated no systematic shifts in  $\delta^{13}\text{C}$  values, and appear to retain their original plant-carbon signature.

Pollen assemblages in marsh sediments also have characteristic signatures which reflect the marsh vegetation community. Discriminant functions can be calculated, using taxa from the marsh communities, which distinguish among the fresh, intermediate, brackish as well as salt marsh salinity zones. Although there are some statistical similarities between fresh and brackish marsh pollen assemblages this can be compensated for by comparison to  $\delta^{13}\text{C}$  values which clearly distinguish these zones. The intermediate marsh, with its high Cyperaceae component, has the most unique pollen assemblage. This factor, in turn, compensates for the overlap in  $\delta^{13}\text{C}$  values between intermediate and brackish/salt marshes.



Processes of water transport are probably the greatest sources of error in both techniques. Transported carbon may dilute the  $\delta^{13}\text{C}$  signature of the autochthonous plant carbon. There are also indications of transport of palynomorphs from fresh to more saline marshes, as well as tidal sources of pollen of non-marsh (extra-regional) taxa. However, in periods during which overbank flooding is likely, the Mississippi River has a pollen assemblage distinguishable from that of coastal marshes and river-born pollen seems to be detectable within the sediments. Although water transport does not cause significant error within the Barataria Basin marshes it could cause the limitation of these techniques in areas with different hydrological characteristics.

There are geographic limitations to both methods, as plant community structure changes. The potential of a distinguishable  $\delta^{13}\text{C}$  signatures for plant communities can be estimated from using measured  $\delta^{13}\text{C}$  values of plant carbon in combination with data on community structure and biomass. The great variability inherent in pollen production and dispersal, however, considerably reduces the potential of estimating characteristics of a pollen assemblage. This study provides an important caveat - that considerable distortion can occur in pollen assemblages in estuarine systems.

Application of these techniques may be limited temporally. Additional research is required to determine if diagenesis does affect  $\delta^{13}\text{C}$  signatures over a period of time greater than 2000 yr B.P. Availability of modern analogues for both  $\delta^{13}\text{C}$  signatures and pollen assemblages may pose a problem where plant community structure has altered due to plant migration, introduction and changes in herbivore populations.

Appendix 1. Pollen and spore counts from LOOP surface marsh sample sites.

plot 1985	volume cc	grains /cc	sample total	count	marker	Indet	Unk	Acer	Alnus	Cabomba	Carya	Celtis	Cheno- Am	Tub	Lig	Compositae Artemisia	Ambrosia	Cornus	Cyperaceae	Decodon	Ericaceae
FC1	0.98	25229	24725	260	127	9	6	1	0	1	0	3	1	1	0	1	6	3	2	16	0
FC2	0.98	18017	17656	250	171	6	3	1	0	0	0	3	2	3	0	1	3	0	9	0	0
FC3	0.98	16282	15957	255	193	7	0	0	0	1	0	2	0	1	0	0	5	0	11	0	0
FC4	0.98	15701	15387	251	197	6	2	2	0	0	0	1	0	8	0	0	4	1	7	0	0
FC5	0.98	17253	16908	238	170	4	3	2	0	1	1	2	0	11	0		1	1	6	0	0
FC6	0.98	18070	17708	261	178	3	2	1	0	0	2	2	1	10	0	1	3	0	16	2	0
FC7	1.80	67631	1E+05	252	25	5	1	1	1	0	0	2	2	11	0	3	4	0	14	1	0
FC8	1.80	1E+05	2E+05	251	13	1	0	0	0	0	2	0	2	7	0	0	5	0	8	0	0
FC9	1.80	73220	1E+05	251	23	3	1	0	2	0	2	5	0	11	0	3	6	0	2	1	0
FC10	0.90	53676	48308	252	63	5	2	1	0	0	0	3	2	18	0	3	2	1	11	0	0
FAA1	0.85	30649	26052	302	140	2	3	2	0	0	1	8	2	2	0	0	11	0	16	0	0
FAA2	0.85	24228	20594	295	173	7	3	4	1	0	1	13	1	2	0	0	3	1	20	0	0
FAA3	0.85	17196	14617	305	252	5	7	3	0	0	2	8	1	6	0	0	8	1	12	1	0
FAA4	0.85	53636	45591	302	80	6	1	1	0	0	0	2	0	4	0	0	4	1	5	0	0
FAA5	0.85	23867	20287	299	178	8	0	1	1	0	0	3	0	2	0	0	7	1	1	1	0
FAA6	0.85	10749	9137	261	345	15	2	0	0	0	0	5	0	1	0	0	6	0	2	0	0
FAA7	0.85	24413	20751	311	181	8	3	0	0	0	1	3	1	0	0	0	5	0	12	1	0
FAA8	0.85	27779	23612	305	156	2	5	2	0	0	1	11	1	0	0	0	9	0	9	0	0
FAA9	0.85	86386	73428	304	50	1	5	2	1	0	0	6	1	4	0	0	8	0	9	0	0
FAA10	0.85	66888	56855	306	65	1	8	1	1	0	2	6	1	2	0	0	7	1	6	0	0
IC1	1.80	22394	40309	257	77	12	0	0	1	0	0	3	34	13	0	0	7	1	28	0	0
IC2	0.90	17569	15812	254	194	7	8	1	2	0	1	0	49	6	0	0	10	1	56	0	0
IC3	0.90	14680	13212	256	234	6	4	1	0	0	1	2	40	12	0	0	13	1	69	0	0
IC4	0.90	20332	18298	250	165	6	6	0	0	0	1	0	6	17	0	0	3	1	128	0	0
IC5	0.90	23483	21135	252	144	9	13	1	0	0	0	1	22	7	0	0	15	0	100	0	0
IC6	0.90	21539	19385	252	157	8	8	2	0	0	1	0	11	10	0	0	22	0	76	0	0
IC7	0.90	40418	36377	250	83	7	7	0	1	0	0	1	41	13	0	1	6	0	84	0	0
IC10	0.90	32589	29330	255	105	7	2	0	0	0	1	2	19	4	0	0	8	0	72	0	0

## Appendix 1.

1985 plot	volume cc	grains /cc	sample total	count	marker	Indet	Unk	Acer	Alnus	Cabomba	Carya	Celtis	Cheno- Am	Compositae					Cornus	Cyperaceae	Decodon	Ericaceae
														Tub	Lig	Artemesia	Ambrosia					
BC1	0.90	22515	20263	250	149	5	4	0	0	0	0	2	11	5	0	4	11	0	8	0	0	
BC2	0.90	18318	16486	258	189	6	3	0	0	0	0	1	8	5	0	0	17	0	30	1	0	
BC3	0.90	22961	20665	308	180	4	4	0	0	0	0	0	27	8	0	2	15	1	9	2	0	
BC4	0.90	39161	35245	286	98	10	2	1	0	0	1	1	33	3	0	0	23	0	14	1	0	
BC5	0.85	75413	64101	276	52	6	3	0	0	0	0	1	16	5	0	1	17	0	12	3	0	
BC6	0.85	40771	34656	264	92	5	1	1	0	0	0	1	48	3	0	0	22	0	5	2	0	
BC7	0.85	21352	18149	269	179	3	4	0	0	0	0	2	23	2	0	0	24	0	3	0	0	
BC8	0.85	48486	41213	273	80	5	3	0	2	0	0	2	34	3	0	0	16	1	3	0	0	
BC9	0.85	40849	34721	276	96	14	1	0	0	0	0	1	10	5	0	0	13	2	7	1	0	
BC10	0.85	57848	49171	285	70	10	3	0	0	0	0	0	100	3	0	1	19	0	5	0	0	
SC1	1.38	55969	77237	275	43	4	1	0	0	0	2	0	33	6	0	0	18	0	19	1	1	
SC2	1.38	32905	45410	282	75	5	2	1	2	1	1	1	37	1	0	0	11	0	18	1	0	
SC3	1.38	30177	41645	300	87	10	3	2	1	0	1	1	45	1	0	0	20	0	15	0	0	
SC4	1.38	32127	44335	279	76	7	4	1	0	0	3	4	37	1	0	0	14	0	18	0	0	
SC5	1.38	47460	65495	282	52	4	3	0	1	0	2	3	37	1	0	0	15	0	9	0	0	
SC6	1.38	20251	27947	280	121	2	2	0	1	0	2	1	36	3	0	0	20	0	11	1	0	
SC7	0.85	28108	23891	273	138	7	4	0	0	0	0	0	35	2	0	0	15	0	13	0	0	
SC8	0.85	30311	25764	288	135	10	7	1	0	1	2	1	48	2	0	0	18	0	14	0	0	
SC9	0.85	39402	33492	269	97	9	5	0	0	0	0	0	26	4	0	1	23	0	12	0	0	
SC10	0.85	55997	47598	268	68	7	2	2	1	0	2	7	35	4	1	0	13	0	23	0	0	
1986																						
FAB3	0.85	14534	12354	312	305	3	5	2	0	0	1	9	2	4	0	0	10	0	6	0	0	
FAB10	0.85	23380	19873	311	189	3	1	0	0	0	1	13	0	8	0	0	4	0	5	1	0	
FBB8	0.85	2E+05	1E+05	337	28	4	2	0	0	0	0	1	1	0	0	0	11	0	3	0	0	
FC2	0.85	34668	29468	305	125	7	1	3	1	0	0	4	4	1	0	0	12	0	13	2	0	
FC10	0.85	2E+05	2E+05	322	23	9	3	2	0	0	0	2	2	11	0	0	7	0	15	1	0	
IC4	0.85	24930	21190	286	163	6	6	0	0	0	0	2	26	6	0	0	25	0	93	0	0	
IC6	0.85	42625	36231	306	102	9	3	1	0	0	0	1	117	5	0	0	18	0	57	1	0	
IPB10	0.85	29600	25160	300	144	3	4	2	0	0	1	1	19	3	0	0	15	0	196	0	0	
BC1	0.85	20101	17086	307	217	10	5	1	1	0	0	0	19	0	0	0	41	0	16	1	0	
BC2	0.85	38088	32374	319	119	8	3	0	2	0	1	1	18	0	0	0	16	0	10	0	0	
BC4	0.85	50913	43276	301	84	1	4	0	0	0	1	0	11	0	0	0	26	0	7	0	0	
SBA1	0.85	46433	39468	317	97	2	5	1	1	0	3	0	45	0	0	0	21	0	26	1	0	
SC8	0.85	62753	53340	318	72	5	3	5	2	0	1	1	32	1	0	0	20	0	21	0	0	
SC10	0.85	37510	31883	330	125	6	5	1	0	0	1	2	58	1	0	0	19	0	31	0	0	

## Appendix 1.

plot 1985	Fraxinus			Juglans	Gramineae	Liquidambar	Morus	Myrica	Myriophyllum	Nymphaeaceae	Nyssa	Osmunda	Plantanus	Polygonum	Pinus	Polypodiaceae
	Euphorbiaceae	3c	4c	5c												
FC1	0	0	1	0	0	56	0	0	4	0	0	0	36	0	0	5
FC2	0	0	1	0	0	34	0	0	3	0	0	0	2	0	0	60
FC3	0	0	4	0	0	17	1	1	7	0	0	0	0	1	0	95
FC4	0	0	0	0	0	11	0	0	4	0	0	0	1	0	0	152
FC5	0	0	1	0	0	31	0	0	7	0	0	0	6	1	2	88
FC6	0	0	2	0	0	20	1	1	8	0	1	0	0	0	0	92
FC7	0	0	2	0	0	10	1	0	9	0	1	0	0	0	1	134
FC8	0	1	0	0	0	5	0	0	4	0	0	0	0	0	0	160
FC9	0	1	2	0	2	6	1	0	7	0	1	1	0	0	0	131
FC10	0	2	4	0	0	23	1	0	5	0	1	0	4	1	0	65
FAA1	0	0	1	3	0	78	0	0	1	0	1	1	0	0	0	5
FAA2	0	0	0	1	0	34	2	0	5	0	1	0	1	0	0	2
FAA3	0	0	1	2	0	69	0	0	2	0	1	1	3	0	0	8
FAA4	0	3	1	1	0	101	2	0	5	0	1	1	0	0	0	19
FAA5	0	0	2	1	0	111	1	0	1	0	1	2	1	0	0	16
FAA6	0	0	1	1	0	122	1	0	4	0	0	0	0	0	0	8
FAA7	0	0	0	0	0	34	0	0	2	0	1	0	0	0	1	111
FAA8	0	2	3	0	0	34	0	0	2	0	0	1	3	0	0	10
FAA9	0	0	2	0	0	57	0	0	8	0	3	2	0	3	0	7
FAA10	0	2	2	0	0	70	2	0	6	0	0	1	1	3	0	10
IC1	0	1	3	0	0	55	2	1	7	0	3	0	6	0	2	21
IC2	1	1	1	0	0	33	1	0	7	0	1	0	1	0	5	7
IC3	0	0	0	0	0	46	1	0	8	0	0	1	1	0	0	1
IC4	0	1	0	0	0	16	0	0	6	0	0	0	1	0	0	1
IC5	0	0	0	0	0	14	0	1	5	0	0	0	0	0	1	4
IC6	0	0	0	0	0	18	2	0	12	0	0	0	0	0	0	1
IC7	0	0	0	0	1	15	1	0	2	0	1	1	0	0	1	3
IC10	0	0	1	0	0	8	0	0	13	0	3	0	2	0	0	7

## Appendix 1.

1985	Fraxinus																	
plot	Euphorbiaceae	3c	4c	5c	Juglans	Gramineae	Liquidambar	Morus	Myrica	Myriophyllum	Nymphaeaceae	Nyssa	Osmunda	Plantanus	Polygonum	Pinus	Polypodiaceae	
BC1		0	0	0	0	1	123	0	0	5	0	2	0	3	0	0	7	14
BC2		0	0	1	0	0	123	0	0	3	0	3	0	1	1	0	14	5
BC3		0	0	3	0	0	104	2	0	8	0	22	0	8	0	0	19	15
BC4		0	1	1	0	0	97	3	0	3	0	4	0	5	0	0	13	30
BC5		0	0	1	0	0	111	1	0	1	1	1	0	6	0	0	13	46
BC6		0	0	0	0	1	72	1	0	5	2	1	0	13	0	0	6	30
BC7		0	0	0	0	0	87	0	0	3	1	1	0	9	0	1	11	44
BC8		0	0	0	1	0	102	0	0	2	0	1	0	15	1	2	10	46
BC9		0	1	0	0	0	137	0	0	2	0	1	0	2	0	2	15	23
BC10		0	0	0	0	0	72	0	0	1	0	1	0	7	0	2	6	29
SC1		0	1	0	1	0	92	1	0	5	0	4	2	1	1	0	22	5
SC2		0	0	0	0	0	77	4	0	7	0	1	0	1	0	0	33	5
SC3		0	2	0	0	1	91	2	0	9	1	3	0	2	0	0	35	5
SC4		0	0	2	1	0	77	6	0	4	1	2	1	2	0	0	30	8
SC5		0	1	2	1	0	77	5	1	5	0	2	0	2	0	0	23	4
SC6		0	2	1	0	1	75	2	0	9	0	1	0	2	0	0	36	4
SC7		0	1	1	1	0	76	2	0	12	0	0	1	1	0	1	21	5
SC8		0	0	0	0	0	91	3	0	8	0	2	0	1	0	1	23	3
SC9		0	1	1	0	0	91	1	0	7	1	0	0	1	0	0	21	4
SC10		0	1	2	0	0	68	3	0	6	1	0	0	1	0	0	26	6
1986																		
FAB3		0	0	0	0	0	24	1	0	5	0	1	0	0	0	0	24	11
FAB10		0	0	2	0	0	77	0	0	4	0	0	0	2	0	0	21	12
FBB8		0	0	0	0	0	10	1	0	2	0	0	0	4	0	0	7	220
FC2		0	0	0	0	0	59	0	0	2	0	1	0	1	0	1	8	120
FC10		0	0	1	0	0	25	0	0	2	0	0	1	2	1	2	9	150
IC4		0	0	0	0	0	13	0	1	9	0	0	0	2	0	3	47	11
IC6		0	0	2	1	0	30	1	0	3	0	1	0	0	0	0	14	3
IPB10		0	0	1	0	0	8	0	0	0	0	1	0	2	0	1	17	0
BC1		0	0	1	1	0	102	2	0	6	0	0	1	7	0	0	9	49
BC2		0	0	0	0	0	162	1	0	2	0	0	0	19	0	0	12	28
BC4		0	0	3	0	0	161	1	0	8	0	0	0	5	0	0	6	29
SBA1		0	0	3	1	0	113	2	0	2	0	1	0	0	0	0	29	3
SC8		0	1	3	0	0	86	1	1	5	1	3	0	1	1	0	50	8
SC10		0	1	6	1	0	89	3	0	2	0	0	0	1	2	0	34	2

## Appendix 1.

plot 1985	Pontedariaceae	Potamogeton	Prunus	Quercus	Sagittaria	Salix	Taxodium	TCT	Typha latifolia	Typha angustifolia	Ulmus	Umbelliferae	Vitis	Vigna	Trilete spores			
															psilate	echinate	verrucate	reticulate
FC1	0	0	1	10	4	7	3	36	0	0	0	2	0	30	0	0	0	4
FC2	0	0	2	10	0	10	5	36	2	0	2	2	0	37	1	0	0	1
FC3	0	0	0	14	6	6	2	38	0	0	1	1	0	15	1	0	1	3
FC4	0	0	0	5	0	14	1	13	0	0	1	3	0	6	0	0	2	2
FC5	0	0	0	6	1	7	2	27	0	0	1	1	0	7	1	0	0	7
FC6	2	0	0	5	4	6	1	24	2	0	0	1	0	3	0	0	19	2
FC7	1	0	0	3	2	3	1	21	2	0	2	0	0	4	0	0	4	3
FC8	2	0	0	3	0	7	1	16	1	2	2	0	0	2	2	0	9	1
FC9	0	0	1	8	1	7	0	12	0	1	0	3	0	3	0	0	10	6
FC10	5	0	0	9	3	13	3	50	0	0	0	5	0	4	0	0	2	2
FAA1	0	1	0	6	1	23	9	105	1	0	0	0	0	2	0	0	0	0
FAA2	0	0	0	12	4	25	12	105	0	0	2	0	0	19	0	0	0	0
FAA3	0	1	0	11	0	20	9	90	1	0	3	0	0	13	0	0	0	0
FAA4	0	3	0	9	3	13	9	71	3	0	1	0	3	11	0	0	0	0
FAA5	0	0	0	6	0	12	5	52	0	0	1	1	0	21	0	0	0	1
FAA6	0	0	0	6	1	12	3	44	0	2	1	0	0	0	1	0	0	0
FAA7	0	0	0	6	9	10	2	44	8	1	0	0	0	41	0	1	0	0
FAA8	0	0	0	6	2	8	6	104	1	0	0	0	0	61	0	0	0	0
FAA9	0	0	0	13	1	15	4	76	0	1	0	6	0	38	0	4	12	0
FAA10	0	0	0	14	0	11	16	73	0	0	0	2	0	28	0	0	0	0
IC1	0	3	0	8	7	6	2	4	0	5	1	0	0	7	0	0	0	1
IC2	1	3	0	6	12	2	0	9	3	3	1	1	0	0	2	0	0	0
IC3	0	5	1	3	11	1	0	6	2	3	0	0	0	1	0	0	0	0
IC4	0	3	0	7	7	1	0	6	4	0	0	0	0	0	0	0	0	0
IC5	1	3	0	9	8	2	2	9	0	3	1	1	0	0	0	0	0	0
IC6	2	0	3	16	2	2	5	10	3	1	0	1	0	0	2	0	1	0
IC7	1	0	0	5	23	3	0	5	2	1	0	1	0	0	0	0	0	0
IC10	1	1	1	10	13	1	0	5	2	1	2	2	0	0	0	0	0	0

## Appendix 1.

1985											Typha	Typha	Trilete spores					
plot	Pontedariaceae	Potamogeton	Prunus	Quercus	Sagittaria	Salix	Taxodium	TCT	latifolia	angustifolia	Ulmus	Umbelliferae	Vitis	Vigna	psilate	echinate	verrucate	reticulate
BC1	0	2	1	5	3	4	1	15	0	3	2	1	0	0	2	0	1	0
BC2	0	0	1	12	3	4	0	7	0	2	3	0	0	0	2	0	0	0
BC3	0	0	0	9	6	6	1	6	0	1	0	0	0	0	2	3	1	1
BC4	0	1	2	5	4	5	2	7	0	1	0	0	2	0	1	0	0	0
BC5	0	1	0	6	5	4	0	7	0	3	0	0	0	0	1	1	0	0
BC6	1	0	0	10	4	6	0	11	0	4	1	0	1	0	1	0	0	0
BC7	0	1	1	13	7	6	1	8	1	2	0	1	0	0	1	1	0	0
BC8	0	3	0	4	4	1	0	1	3	1	0	1	0	0	2	0	0	0
BC9	3	3	0	5	8	0	2	6	2	1	0	0	0	0	1	0	0	2
BC10	1	0	1	4	0	5	0	3	2	1	3	1	0	0	0	0	0	0
SC1	2	1	0	17	6	4	2	7	0	9	3	0	0	0	0	0	0	0
SC2	0	2	0	37	2	6	2	10	1	10	1	0	0	0	1	0	0	0
SC3	0	0	2	23	0	2	3	5	3	10	1	0	0	0	0	0	0	0
SC4	2	1	0	25	1	2	3	8	2	8	0	0	0	0	0	0	1	0
SC5	0	1	1	44	1	1	0	12	3	17	3	0	1	0	0	0	0	0
SC6	0	0	0	25	2	7	2	8	0	20	2	0	0	0	0	0	0	0
SC7	1	0	2	22	4	6	1	15	1	20	2	0	0	0	1	0	0	0
SC8	1	0	0	12	4	6	4	9	0	13	0	0	0	0	2	0	0	0
SC9	1	2	1	18	4	2	0	14	0	18	1	0	0	0	0	0	0	0
SC10	0	3	0	16	1	6	3	17	1	7	0	0	0	1	0	0	0	0
1986																		
FAB3	0	1	0	13	3	28	4	86	1	0	0	1	1	62	0	0	0	0
FAB10	0	0	0	16	0	16	4	86	0	0	0	0	0	27	0	0	0	0
FBB8	0	0	0	0	9	2	0	15	2	0	2	2	0	4	0	22	10	1
FC2	0	0	0	5	0	1	0	14	0	1	1	2	0	40	0	0	0	0
FC10	0	0	0	4	1	5	2	37	0	2	0	2	1	1	0	6	10	0
IC4	0	0	0	12	7	6	0	6	2	0	0	0	0	1	0	0	0	0
IC6	0	0	1	7	2	3	1	10	1	6	1	1	0	1	1	0	0	0
IPB10	0	0	0	9	3	4	0	5	0	3	0	0	0	2	0	0	0	0
BC1	0	0	0	10	4	1	1	9	0	2	2	0	0	0	0	0	1	0
BC2	0	0	0	9	3	1	0	4	2	1	1	0	0	0	0	2	2	0
BC4	0	0	0	8	2	2	0	6	1	1	1	1	0	0	1	2	1	0
SBA1	2	0	0	11	1	3	1	8	1	23	0	0	0	0	0	0	0	0
SC8	0	1	0	19	1	5	2	17	0	12	5	1	0	0	0	0	0	0
SC10	0	1	1	14	4	5	0	14	3	17	2	0	0	1	0	0	0	0

Appendix 1.

plot 1985	Trilete spores		Populus	Equisetum	Hymenocallis	Tilia	Cuscuta	Fagus	Corylus	Bacopa	Sphagnum	Picea	Limnium	Malvaceae	Rhexia	Betula	Ostrya	Cephalanthus
	bacculate	scabrate																
FC1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
FC2	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
FC3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FC4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FC5	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
FC6	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
FC7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FC8	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
FC9	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FC10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FAA1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
FAA2	0	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
FAA3	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
FAA4	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FAA5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
FAA6	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FAA7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FAA8	0	0	3	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
FAA9	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FAA10	0	0	4	0	0	0	0	0	0	3	0	0	0	0	0	0	1	0
IC1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
IC2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
IC3	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0
IC4	0	0	0	0	0	0	0	0	1	17	0	0	0	0	0	0	0	0
IC5	0	0	0	0	0	0	1	1	1	3	0	0	0	0	0	0	0	0
IC6	0	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0
IC7	0	0	0	0	0	0	1	0	0	13	0	0	0	0	0	0	0	0
IC10	0	0	0	0	0	0	0	0	0	61	0	0	0	0	0	0	0	0



## Appendix 1.

1985 plot	Trilete spores		Populus	Equisetum	Hymenocallis	Tilia	Cuscuta	Fagus	Corylus	Bacopa	Sphagnum	Picea	Limnium	Malvaceae	Rhexia	Betula	Ostrya	Cephalanthus
	bacculate	scabrate																
BC1	0	0	1	0	0	0	2	1	0	1	0	0	0	0	0	0	0	0
BC2	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
BC3	1	1	0	0	0	0	0	0	0	0	17	0	0	0	0	0	0	0
BC4	0	0	3	0	0	0	0	0	0	1	5	1	0	0	0	0	0	0
BC5	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0
BC6	1	0	1	0	0	0	0	0	0	0	3	0	1	0	0	0	0	0
BC7	1	1	1	0	0	0	0	1	0	0	4	0	0	0	0	0	0	0
BC8	0	0	2	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0
BC9	0	0	4	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0
BC10	0	0	2	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0
SC1	0	0	2	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0
SC2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
SC3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC4	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
SC5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC6	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
SC7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC8	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC10	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
1986																		
FAB3	0	0	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
FAB10	0	0	2	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
FBB8	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0
FC2	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
FC10	0	0	1	2	0	0	0	1	1	0	0	0	0	0	0	0	0	0
IC4	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
IC6	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0
IPB10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BC1	2	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
BC2	10	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BC4	4	0	2	1	0	0	0	0	0	0	3	0	0	0	0	0	0	0
SBA1	0	1	1	0	0	0	0	0	4	0	1	0	0	0	0	0	0	0
SC8	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
SC10	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0

Appendix 1.

plot 1985	Plantago	Rumex	Lythraceae	Zanthoxylum	Urtica	Lycopodium
FC1	0	0	0	0	0	0
FC2	0	0	0	0	0	0
FC3	0	0	0	0	0	0
FC4	0	0	0	0	0	0
FC5	0	0	0	0	0	0
FC6	0	0	0	0	0	0
FC7	0	0	0	0	0	0
FC8	0	0	0	0	0	0
FC9	0	0	0	0	0	0
FC10	0	0	0	0	0	0
FAA1	0	0	0	0	0	0
FAA2	0	0	0	0	0	0
FAA3	0	0	0	0	0	0
FAA4	0	0	0	0	0	0
FAA5	0	0	0	0	0	0
FAA6	0	0	0	0	0	0
FAA7	0	0	0	0	0	0
FAA8	0	0	0	0	0	0
FAA9	1	0	0	0	0	0
FAA10	0	0	0	0	0	0
IC1	0	0	0	0	0	0
IC2	0	0	0	0	0	0
IC3	0	0	0	0	0	0
IC4	0	0	0	0	0	0
IC5	0	0	0	0	0	0
IC6	0	0	0	0	0	0
IC7	0	0	0	0	0	0
IC10	0	0	0	0	0	0

Appendix 1.

1985 plot	Plantago	Rumex	Lythraceae	Zanthoxylum	Urtica	Lycopodium
BC1	0	0	0	0	0	0
BC2	0	0	0	0	0	0
BC3	0	0	0	0	0	0
BC4	0	0	0	0	0	0
BC5	0	0	0	0	0	0
BC6	0	0	0	0	0	0
BC7	0	0	0	0	0	0
BC8	0	0	0	0	0	0
BC9	0	0	0	0	0	0
BC10	0	0	0	0	0	0
SC1	0	0	0	0	0	0
SC2	0	0	0	0	0	0
SC3	0	0	0	0	0	0
SC4	0	0	0	0	0	0
SC5	0	0	0	0	0	0
SC6	0	0	0	0	0	0
SC7	0	0	0	0	0	0
SC8	0	0	0	0	0	0
SC9	0	0	0	0	0	0
SC10	0	0	0	0	0	0
1986						
FAB3	1	0	0	0	0	0
FAB10	0	4	0	0	0	0
FBB8	0	0	0	0	0	0
FC2	0	0	0	0	0	0
FC10	1	0	0	0	0	0
IC4	0	0	1	0	0	0
IC6	1	0	1	0	0	0
IPB10	0	0	0	0	0	0
BC1	0	0	0	2	0	0
BC2	0	0	0	0	0	0
BC4	0	0	1	1	0	0
SBA1	0	0	0	0	1	0
SC8	0	0	0	0	0	0
SC10	1	0	0	0	0	1

Appendix 2. Pollen and spore counts from Falgout Canal core, Terrebone Parish Louisiana.

sample	Depth volume grains sample					Cheno										Compositae				Fraxinus				
	cm	cc	/cc	total	count	marker	Indet	Unk	Acer	Alnus	Carya	Celtis	-Am	Tub	Ambrosia	Artemesia	Cornus	Cyperaceae	3c	4c	5c	Juglans		
24	214	1.00	48017	48017	330	83	26	4	3	0	3	0	15	3	7	0	0	5	3	3	1	0		
23	217	1.00	27945	27945	317	137	11	5	0	1	4	0	5	2	9	0	0	2	4	1	0	0		
22	223	0.82	87235	71533	308	52	13	6	0	0	1	1	2	0	8	0	0	4	1	2	0	0		
21	228	1.00	1E+05	1E+05	307	35	9	2	0	0	0	10	8	0	14	0	0	3	1	2	0	0		
20	234	1.00	69443	69443	299	52	13	7	1	0	1	1	14	1	6	0	0	5	5	3	1	0		
19	238	1.00	49287	49287	302	74	15	6	2	1	1	2	15	0	11	0	0	3	4	1	1	0		
18	247	1.00	46437	46437	273	71	13	8	1	1	2	1	11	2	11	0	0	4	2	1	2	0		
17	254	1.00	22579	22579	301	161	8	0	0	0	0	2	9	1	13	0	0	1	5	3	0	0		
16	278	1.00	3E+05	3E+05	317	14	16	2	0	0	0	2	6	3	4	0	0	11	1	0	0	0		
15	289	1.00	80601	80601	307	46	8	7	0	2	9	0	16	13	20	0	0	59	4	1	1	0		
14	307	1.00	2E+05	2E+05	589	47	13	8	3	1	1	3	82	7	6	0	0	95	4	2	1	0		
13	317	1.00	2E+05	2E+05	626	40	5	9	1	1	3	1	103	2	7	0	2	323	1	2	0	1		
12	328	1.00	2E+05	2E+05	338	20	7	0	0	0	0	1	12	2	1	2	0	225	0	1	0	0		
11	348	1.00	5E+05	5E+05	1355	32	26	12	3	0	1	1	312	3	16	0	0	127	0	3	0	1		
10	356	1.00	2E+05	2E+05	397	24	14	3	0	0	1	1	255	6	9	1	0	3	1	1	0	1		
9	373	1.00	46367	46367	215	56	13	10	1	1	1	3	6	2	15	0	0	7	2	0	0	0		
8	396	1.00	90242	90242	269	36	4	6	0	1	2	3	10	14	32	1	0	23	1	3	0	0		
7	405	1.00	62398	62398	279	54	9	2	0	0	4	1	33	4	30	4	0	3	7	0	0	0		
6	415	1.00	28110	28110	270	116	6	5	1	1	2	4	34	6	15	0	0	12	4	4	0	0		
5	425	1.00	31328	31328	262	101	6	5	1	1	4	2	43	12	19	1	1	11	3	3	0	0		
4	434	1.00	47144	47144	324	83	11	5	8	0	3	1	45	8	18	2	0	26	6	2	1	1		
3	444	1.00	42350	42350	263	75	0	1	0	0	3	1	73	0	2	0	0	110	1	1	1	0		
2	454	1.00	48308	48308	272	68	14	4	0	0	0	0	25	3	1	0	0	60	2	4	0	0		
1	494	1.00	96012	96012	318	40	8	1	0	0	3	3	41	14	2	0	0	42	3	2	0	0		

Appendix 2.

sample	Gramineae	Liquidambar	Myrica	Nymphaeaceae	Nyssa	Polygonum	Pinus	Polypodiaceae	Potamogeton	Prunus	Quercus	Sagittaria	Salix	Tax	TCT type
24	166	5	0	0	0	0	25	3	1	1	21	0	1	0	20
23	177	8	2	0	0	0	32	3	0	1	22	1	2	0	12
22	205	1	1	0	1	0	19	2	1	0	17	0	0	0	15
21	185	0	1	2	2	0	19	5	0	0	22	0	1	2	14
20	130	3	3	0	3	1	25	2	0	0	33	0	1	1	26
19	145	5	1	0	0	0	23	2	0	0	11	0	1	4	35
18	148	2	3	0	1	0	30	2	0	0	11	0	0	2	7
17	184	5	0	0	0	0	12	0	0	0	21	0	0	3	29
16	241	0	0	0	0	0	5	0	0	0	5	0	0	0	16
15	109	1	3	0	1	0	14	3	0	1	7	0	1	2	20
14	237	5	1	0	1	0	22	7	0	0	30	0	1	5	38
13	82	4	0	0	0	3	15	1	0	0	16	0	6	1	28
12	50	2	0	0	0	0	9	2	0	0	13	0	0	1	7
11	735	0	0	0	1	0	27	4	0	1	23	0	4	8	27
10	34	1	0	0	2	0	21	1	0	0	17	0	0	0	16
9	35	0	0	0	1	0	31	1	0	0	37	0	3	2	39
8	42	10	3	0	0	0	29	1	0	0	32	0	8	2	36
7	21	5	0	0	1	0	33	0	0	0	38	0	7	1	61
6	14	4	1	0	1	0	17	0	1	0	38	0	5	0	86
5	18	4	0	0	0	1	24	12	0	0	36	0	5	0	37
4	26	3	0	0	0	0	28	1	0	1	36	0	8	6	63
3	20	0	0	0	0	0	6	1	0	0	8	0	0	1	28
2	71	4	0	0	0	0	7	2	0	1	5	0	2	0	33
1	118	1	0	0	0	0	10	1	0	1	11	0	5	0	28

Appendix 2.

sample	Typha		Ulmus	Umbelliferae	trilete spores			Fagus	Betula	Ostrya	Plantago	Carpinus	Ludwigia	Bacopa
	latifolia	angustifolia			Vigna	verrucate	psilate							
24	1	6	3	1	0	0	0	0	0	0	1	1	0	0
23	3	5	3	0	0	0	0	0	0	0	1	0	0	0
22	1	5	0	0	0	0	0	0	0	0	0	1	0	0
21	0	3	0	0	0	0	0	0	0	0	0	1	0	0
20	2	7	0	0	0	0	1	0	1	0	0	1	0	0
19	2	5	1	0	0	0	1	0	1	0	0	0	0	1
18	1	3	1	1	0	0	1	0	0	0	0	0	0	0
17	1	1	2	0	0	0	0	0	0	0	0	0	0	0
16	0	2	0	0	0	0	0	0	0	0	0	0	0	1
15	0	1	0	0	0	0	0	1	0	0	0	0	1	0
14	2	8	3	0	0	1	0	1	0	0	0	0	0	0
13	1	6	1	0	0	0	0	0	0	1	0	0	0	0
12	2	0	0	0	0	0	0	0	0	0	0	0	0	0
11	2	6	2	2	0	0	0	0	0	0	4	0	0	0
10	1	1	4	0	0	0	0	0	0	0	0	0	0	0
9	0	2	0	1	0	0	0	0	1	0	1	0	0	0
8	1	1	0	0	0	0	0	1	1	0	0	0	0	0
7	1	3	7	0	0	0	0	1	2	0	0	0	0	0
6	0	4	0	0	0	0	0	3	0	0	0	0	0	0
5	0	7	3	0	0	0	0	1	0	0	0	1	0	0
4	0	4	3	6	0	0	0	0	0	0	0	0	0	0
3	0	4	0	0	0	0	0	0	0	0	0	0	0	0
2	0	10	1	0	22	0	0	0	0	0	0	0	0	0
1	0	21	0	3	0	0	0	0	0	0	0	0	0	0

## VITA

Gail Lois Chmura was born in Pawtucket, Rhode Island on October 12, 1953. She graduated magna cum laude from the University of Massachusetts with Bachelor of Science in wildlife biology in 1975. The same year she began her master's research on tidal salt marsh soils within the Department of Plant and Soil Science at the University of Rhode Island. During her master's program she took a hiatus to serve as a biologist with the Rhode Island Coastal Zone Management Program. After returning to the University of Rhode Island in 1981 she was awarded a National Sea Grant Fellowship. This supported her year as a legislative assistant with the U.S. House of Representatives Committee on Merchant Marine and Fisheries, Subcommittee on Fisheries and Wildlife Conservation and the Environment. In 1982 she graduated from the University of Rhode Island, much to the relief of the graduate dean. Ms. Chmura worked for an additional year with the Rhode Island Coastal Zone Management Program before returning to the University of Rhode Island for a year of coursework in geology. In 1984 she entered the Department of Marine Sciences at Louisiana State University and later selected for the Joe Lipsey, Sr. Memorial Scholarship by that Department. During the 1988-89 academic year she conducted research at the Netherlands Institute for Sea Research, supported by a Fulbright Fellowship.

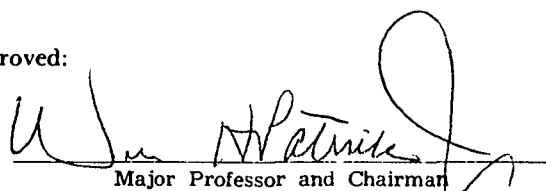
DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate: Gail Lois Chmura

Major Field: Marine Sciences

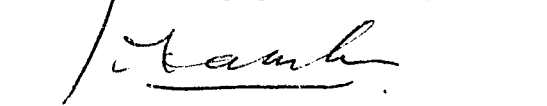
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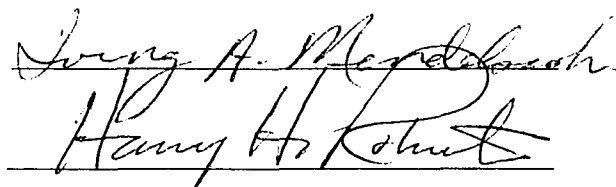
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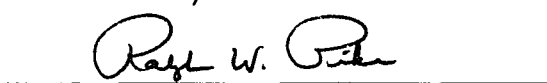
  
Major Professor and Chairman

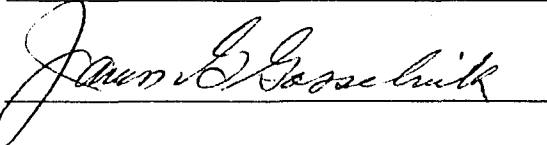
  
Dean of the Graduate School

EXAMINING COMMITTEE:











Date of Examination:

December 8, 1989